Evolution of design for sustainability: From product design to design for system innovations and transitions

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The paper explores the evolution of Design for Sustainability (DfS). Following a quasi-chronological pattern, our exploration provides an overview of the DfS field, categorising the design approaches developed in the past decades under four innovation levels: Product, Product-Service System, Spatio-Social and Socio-Technical System. As a result, we propose an evolutionary framework and map the reviewed DfS approaches onto this framework. The proposed framework synthesizes the evolution of the 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 visualises linkages, overlaps and complementarities between these approaches.

Keywords: design for sustainability, innovation, product design, design research, literature review

The famous Brundtland Report coined one of the most frequently cited definitions of sustainable development in 1987 as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (World Commission on Environment and Development (WCED, 1987: p 43)). 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. This is perhaps due to dependence of human society on ecosystem services both for meeting primary biological needs and for providing resources that are needed for economic and technological development (Gaziulusoy, 2010). Studies have shown that our theoretical understanding of the concept has evolved from a view that perceived sustainability as a static goal to a dynamic and moving target responding to our ever increasing understanding of interdependencies between social and ecological systems. Since operationalisation of

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sustainability required temporal and spatial context-specific indicators, it was also realised that there cannot be an overarching all-encompassing specific sustainability target to strive for (Faber, Jorna, & Van Engelen, 2005; Hjorth & Bagheri, 2006).

The current understanding suggests that sustainability is a system property and not a property of individual elements of systems. Therefore 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 (Bagheri & Hjorth, 2007; Clayton & Radcliffe, 1996; Holling, 2001; Walker, Holling, Carpenter, & Kinzig, 2004). With the increasingly fast decline of both terrestrial and aquatic ecosystems and declining biodiversity (Butchart et al., 2010; Rockström et al., 2009), the extent and urgency of action required to mitigate and adapt to climate change (Hughes & Steffen, 2013), and alarming estimates of economic and social cost of inaction for addressing global and pressing environmental issues (MEA, 2005; Stern, 2006), the present emerging view is that there is a need for radical transformational change in how human society operates (Ryan, 2013a, 2013b). This radical change is accepted to require not only technological interventions but also social, cultural/behavioural, institutional and organisational change (Geels, 2005a; Loorbach, 2010).

In line with the contextual changes and theoretical developments that have taken place, the response from the broader society in general and from business, as one of the key stakeholders of these changes, has also evolved in the past decades, with an increasing pace in the past ten to 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 & Wijsman, 2013; Metcalf & Benn, 2012; Parrish, 2007).

Design, as a primary function for innovation in business and increasingly in government and in other social organisational units including local communities (Design Council, 2007; Gruber, de Leon, George, & Thompson, 2015; Meroni, 2007; Ryan, 2008) has been engaged with different aspects of sustainability discourse and practice sporadically since mid-twentieth century thanks to pioneers like Buckminster Fuller and Victor Papanek. 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 provide an overview of the evolution of the response from the design discipline to sustainability issues which marks the broad field of Design for Sustainability (DfS). Our exploration follows a quasi-chronological pattern. The paper is structured as follows. In the following sections (1–4) we present the DfS approaches which have emerged in the past decades. These are categorised in four different innovation levels:

- *Product innovation level:* design approaches focussing 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 focussing 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.

For each DfS approach, we discuss how it was developed and who have been the main contributors, its strengths and limitations, and the future research challenges to be addressed. Table 1, at the end of Section 4, provides an overview of the main characteristics of these DfS approaches. Building upon the analysis of DfS approaches, in Section 5 we reflect on the evolution of the DfS field, we propose a framework that synthesizes this evolution and we discuss the linkages, overlaps and complementarities between the various DfS approaches.

1 Product design innovation level

1.1 Green design and ecodesign

Earliest concerns about resource limits and the impact of our material production on the environment are often traced back to Buckminster Fuller's teachings and work (Fuller, 1969). However, the seminal work introducing environmental considerations into the world of designers is considered to be Victor Papanek's book 'Design for the Real World: Human Ecology and Social Change' (Papanek, 1985). Papanek provided an in-depth critique of the design profession pointing out its role in encouraging consumption and therefore contributing to ecological and social degradation. His work reflected a sophisticated response focussing not only improving the outputs of design activity but promoting transformation of the design profession. Nevertheless, the following early adoption of 'green' attitudes in the design profession had not demonstrated a similarly high desire for transformational change. The early examples of **green design** practice (Burall, 1991; Mackenzie, 1997) primarily focused on lowering environmental impact through redesigning individual qualities of individual products. This was usually achieved by following the waste hierarchy of reduce-reuse-recycle (e.g. reducing amount of material used in a product, re-using parts or whole products in design of new products, replacing virgin materials with recycled materials, replacing hazardous/toxic materials with non-hazardous ones). This period also saw early designs focussing on use of renewable energy such as solar street lamps (Fuad-Luke, 2002). For others, considering environment in design meant efficiency improvements in product and process engineering (e.g. Fiksel, 1996; OECD, 1998). 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 & Kremer, 2011). Although introducing the 'green' prefix to the lexicon of the design profession, and developing and improving the still valid 'rules of thumb' for improving environmental performance of products, green design lacked material and political depth, therefore, promoted green consumerism and did not present a significant capacity for generating environmental gain (Madge, 1997).

Green design example

Earlier examples of green design include Berol's Karisma coloured pencil series which replaced toxic paint that was used to indicate the colour of the pencil with non-toxic transparent resin. The colour of the pencils was instead indicated by cutting the end of the pencil diagonally to make it easy to see the coloured core (Image web link: https://s-media-cache-ak0.pinimg.com/736x/87/32/c1/8732c1a4bd859fe9f17649f997423a7d.jpg).

Other examples include furniture and other products made by discarded and shredded TetraPak containers which are essentially non-recyclable and upcycling discarded front-loader washing-machine drums into bookshelves and alike (Image web link: e: http://www.ticotimes.net/2010/11/11/dairy-giant-recycles-tetra-pak-into-school-desks).

Used synonymously with green design when first introduced, **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 (Boks & McAloone, 2009; Pigosso, McAloone, & Rozenfeld, 2015; Tischner & Charter, 2001). This enabled profiling the environmental impact of products across all life-cycle phases, identifying those phases with the highest environmental impact and therefore provided strategic direction for design interventions. The life-cycle approach of ecodesign has been supported by life-cycle assessment methods. These help with quantification of environmental impacts, enabling meaningful comparison between different product concepts of the same category and therefore helping with design decision making (Andersson, Eide, Lundqvist, & Mattsson, 1998; EEA, 1997; Bhander, Hauschild, & McAloone, 2003; Millet, Bistagnino, Lanzavecchia, Camous, & Poldma, 2006; Nielsen & Wenzel, 2002). The overall goal of ecodesign is to minimise the consumption of natural resources and energy and the consequent impact on the environment while maximising benefits for customers. 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 & van Hemel, 1997; Binswanger, 2001). On a more practical side, a fairly complete set of ecodesign principles, guidelines and tools has been developed (e.g. Bhamra & Lofthouse, 2007; Tischner & Charter, 2001; Vezzoli & Manzini, 2008). As highlighted by Pigosso et al. (2015), in the last decade ecodesign went through a process of consolidation of knowledge and tools, and currently research is focussing on expanding the traditional ecodesign scope towards the more managerial and strategic issues linked to ecodesign implementation (e.g. Fargnoli, De Minicis, & Tronci, 2014; Pigosso, Rozenfeld, & McAloone, 2013), as well as on eco-design decision support systems (e.g. Romli, Prickett, Setchi, & Soe, 2015).

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 most major companies, especially for those producing energy using products.

Although the life-cycle focus of ecodesign provides significant strengths over early practice of green design, it also has significant shortcomings. Lacking complexity, ecodesign focuses solely on environmental performance (Gaziulusoy, 2015) and therefore disregards social dimensions of sustainability which cover issues around the distribution of resources and the product's social impacts related that cannot be accounted for in life-cycle assessments. Although early implementations of ecodesign resulted in huge environmental gains, once the inefficiencies and 'bad design' were removed from products, the gains started to become marginal and increasingly costly, resulting in ecodesign becoming problematised (Ryan, 2013a, 2013b). Moreover, the efficiency gains on a product basis did not resolve the impacts associated with ever increasing consumption of products which outpaced unit efficiency improvements (Ryan, 2002, 2003). In addition, although ecodesign is supposed to focus on the whole life-cycle, this is mainly done from a technical perspective, with a limited attention to the human related aspects (e.g. user behaviour in the use phase) (Bhamra, Lilley, & Tang, 2011).

Ecodesign example

Fria (designed by Ursula Tischner) is a multi-chamber refrigerator meant to be installed near the (northern) exterior wall of the house. It is designed to use the cold outside air to cool the compartments in winter, reducing in this way the energy consumption by 50% compared to conventional refrigerators. The refrigerator is designed with a modular architecture: the cooling system is independent from the chambers, which can be repaired or replaced separately, leading to a longer lifespan (Additional details/images in: Tischner & Charter, 2001).

1.2 Emotionally durable design

Ecodesign offers several design strategies to extend product lifespan (e.g. Charter & Tischner, 2001; Van Hemel & Brezet, 1997). However, for some product categories, the end of lifespan is not caused by technical issues. It has been estimated that 78% of discarded products still function properly when replaced (Van Nes, 2003), and in some cases this is due to psychological obsolescence (when a product is discarded for reasons such as changes in users' perceived needs, desire for social status emulation, or new trends in fashion and style) (Cooper, 2004, 2010). 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. Chapman, 2005; Chapman, 2009; Mugge, 2007; Van Hemel & Brezet, 1997; Van Hinte, 1997). Common labels used to define this field of research are *Emotionally durable design* and *Design for product attachment*.

User-product attachment requires the presence of an emotional connection between the user and a product (Schifferstein & Zwartkruis-Pelgrim, 2008). 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 to stimulate product attachment through the previously mentioned determinants (e.g. Chapman, 2005; Mugge, 2007; Mugge, Schoormans, & Schifferstein, 2005; Salvia, Ostuzzi, Rognoli, & Levi, 2010). 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).

The emotionally durable design approach offers a set of design strategies complementary to other approaches in the DfS field. However, there are some important limitations to be considered. First of all, for designers it is particularly challenging to effectively stimulate product-attachment. They can apply appropriate design strategies but in the end it is the user who gives a particular meaning to a product (Mugge, 2007). Cultural, social, and personal factors can generate different meanings and different degrees of attachment (Chapman, 2005; Kazmierczak, 2003). Also, product attachment determinants are less relevant for some product categories (e.g. products which are purchased mainly for utilitarian reasons, for instance a washing machine) (Mugge et al. 2005). In addition, for some product categories extending longevity beyond a certain point might not be environmentally beneficial (e.g. for products whose main impact is in the use phase) (Vezzoli & Manzini, 2008). Finally, manufacturers might be averse to implement product attachment strategies because this might lead to reduced sales (Mugge et al. 2005).

Past research has focused on investigating product attachment mainly through questionnaires, interviews or limited time span longitudinal studies. Studies exploring product attachment during the whole lifespan of a product might lead to a better understanding of the factors determining product attachment and detachment (Mugge, 2007). Also, further research is required to test the effectiveness of implementing these strategies in different product categories. Finally, the role of culture and user values in developing product attachment is another area that requires additional research (Mugge, 2007).

Emotionally durable design example

Do Scratch (Droog Design) is a black painted lamp. Users can scratch the surface to liberate the areas where the light can pass through. This allows users to personalise their lamp and to create a unique product. Self-expression and product uniqueness are two factors that can potentially extend the emotional bond between the user and the lamp (Image web link: https://thedailypoetics.files.wordpress.com/2007/08/media_httpdailypoetic_dfjbu-scaled5001.jpg?w=300&h=300; Additional details/images at: http://www.guixe.com/products/DROOG_do_scratch/do_scratch.html).

1.3 Design for sustainable behaviour

An ecodesign approach can provide designers with a set of design strategies to reduce the environmental impact of a product throughout its whole life cycle (Pigosso et al., 2015). However, this approach does not devote much attention to the influence that users' behaviour can have on the overall impact of a product. The way in which consumers interact with products can produce substantial environmental impacts (Environmental Change Unit, 1997; Sherwin & Bhamra, 1998). For example, for products that consume energy in use, energy consumption is mainly determined by user's behaviour (Tang & Bhamra, 2009). For this reason, design researchers have started to explore the role of design in influencing user behaviour (e.g. Lilley, 2007; Rodriguez & Boks, 2005; Wever, van Kuijk, & Boks, 2008), and subsequently to develop approaches, tools and guidelines that explicitly focus on design for sustainable behaviour (e.g. Bhamra et al., 2011; Lilley, 2009; Lockton, Harrison, & Stanton, 2010; Zachrisson & Boks, 2012). These approaches and tools are built upon various behaviour change theories. As noted by Niedderer et al. (2014) there are many different design for behaviour change approaches because there are many different models of behaviour change in social sciences. For example: the Design for Sustainable Behaviour model developed at *Loughborough University* (Bhamra et al., 2011; Lilley, 2009) is grounded on behavioural economics and proposes a set of design intervention strategies based on informing, empowering, providing feedback, rewarding and using affordances and constraints; *Design with Intent* (Lockton, 2013; Lockton et al., 2010) draws from a variety of fields and proposes eight lenses (Architectural, Errorproofing, Interaction, Perceptual, Cognitive, Security, Ludic and Machiavellian lenses) by which to understand and influence aspects of personal behaviour and contexts.

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 it easier for people to adopt a desired behaviour;
- making it harder for people to perform an undesired behaviour;
- making people want a desired behaviour;
- making people not want an undesired behaviour.

Currently, examples of applications of design for sustainable behaviour that can be found in the literature are targeted at the environmental dimension (i.e. stimulating users to adopt more environmentally sustainable patterns of use, e.g. Tang and Bhamra (2012)), and/or the social dimension (i.e. enabling users to adopt a healthier-lifestyle, e.g. Ludden and Offringa (2015)), or acting more safely in built environments (e.g. Pucher and Buehler (2007)). Applications span from product to product-service system, mobile interaction and built environment design.

DfSB presents some important challenges and limitations. First of all, the ethical implications of applying DfSB should better explored and discussed: there is in fact a concern regarding the extent to which designers and companies are entitled to drive user behaviour (Berdichevsky & Neuenschwander, 1999; Brey, 2006; Bhamra et al., 2011). Also, there is currently a lack of metrics to measure the effect of DfSB strategies and a lack of evidence based examples (Niedderer et al., 2014). Linked to this, there is also the need of a better understanding of environmental trade-offs. Implementing DfSB might require the use of additional materials and resources, and the related environmental impact might be higher than the supposed environmental gain (e.g. Wever, Van Onselen, Silvester, & Boks, 2010). Finally, business stakeholders might not be incentivised in implementing DfSB strategies because the investment required might not be counterbalanced by immediate financial gains (Lilley, 2009; Niedderer et al., 2014).

Niedderer et al. (2014) in their review of DfSB identified some key research challenges to be addressed. These include: the development of assessment metrics and techniques for a systematic analysis and evaluation of examples; the testing of the effectiveness of DfSB strategies and the development of evidence based examples (e.g. as done by Zachrisson, Goile, Seljeskog, and Boks (2016) in relation to woodstoves); and the development of a language more accessible to professionals. Another review by Coskun, Zimmerman, and Erbug (2015) concluded that future research in DfSB area should expand the scope of behaviours, user groups and context research focuses. Coskun et al. (2015) and Wever (2012) also pointed to a need for identifying the DfSB strategies that are most likely to be effective to address sustainability depending on particular situations (in relation to this see the work done by Zachrisson and Boks (2012)). From a more operational and organizational perspective, another challenge highlighted by Wever (2012) is on how to integrate DfSB approaches in existing innovation processes.

Design for sustainable behaviour example

Power-aware cord (The Swedish Interactive Institute) is a powercord that visualises energy consumption through patterns of glowing and pulsating light: the higher the energy usage, the faster the flow of light. This allows users to be aware of and reflect on the energy consumption of electrical devices, potentially adopting more sustainable behaviours (Image web link: http://designapplause.com/wp-content/xG58hlz9/2010/06/power-aware1.png; Additional details/images at: http://www.poweraware.com/en/).

1.4 Nature-inspired design: cradle-to-cradle design and biomimicry design

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

CTC has been pioneered and advocated by architect William McDonough and chemist Michael Braungart based on two interrelated concepts: *food equals waste* and *eco-effectiveness* (Braungart, McDonough, & Bollinger, 2007; McDonough & Braungart, 2002). Eco-effectiveness puts emphasis on a regenerative (rather than depletive) approach by industry. It is operationalised with the 'waste equals food' framework which defines two types of nutrients: biological and technological. The assumption underlying CTC design is that if these nutrients are used in open (for biological nutrients) or closed (for technological nutrients) loops, human society can continue production, consumption and economic growth indefinitely. The potential of CTC design in enabling radical innovation and creating mind-set change in businesses towards achieving sustainability has been acknowledged as its main value (Bakker, Wever, Teoh, & Clercq, 2010). It also puts emphasis on regenerative processes, non-human species and future generations. Nevertheless, it is argued that these emphases remain at a rhetorical level and, despite its inspiring vision, CTC design is technically not very well justified (Gaziulusoy, 2015). For example, the premise of CTC design that wastes and emissions from biological materials are ecologically irrelevant because these decompose and become 'nutrients' is not justified as increases in concentrations of biological nutrients have ecological effects and high concentrations may in fact create a human health hazard (Reijnders, 2008). In terms of technological nutrients, even if it would be possible to establish 100% efficient cycles with no material quality or quantity loss, these cycles would need to be fed with new virgin materials in order to feed the promised continuous growth (Bjørn & Hauschild, 2013). Finally, CTC design might shift focus of design decisions from the entire life-cycle of products to minimising or eliminating toxic materials, therefore, potentially result in overlooking impacts of energy consumption (Bakker et al., 2010; Llorach-Massana, Farreny, &

Oliver-Solà, 2015). This is a particularly significant issue for products which consume energy during the use phase (Llorach-Massana et al., 2015).

> **Cradle to Cradle design example**
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> Nike Considered is a line of shoes integrating Cradle to Cradle principles. For example: they are designed to be more easily recycled by using mechanical interlocking systems instead of adhesive (in particular for the outsole); they are made from materials sourced close to the factory; they have a relatively high content of renewable materials such as hemp and cotton fabric (Image web link: https://upload.wikimedia.org/wikipedia/en/8/82/NikeConsideredBoot.jpg).

The premise of BM design (also known as Biomimetics, Bio-inspired design and Bionics (Vincent, 2009)) is using nature as model, measure and mentor (Benyus, 1997). 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 learnt what works and what is appropriate. Using nature as a mentor puts emphasis on learning from nature rather than exploiting it. BM design defines three theoretical and practical levels of biomimicry (Benyus, 1997): first is mimicking *forms* of nature, second is mimicking *processes* of nature and third is mimicking *ecosystems*. BM design, similar to CTC design, 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. the Chakrabarti System (a database providing analogical ideas for design (Chakrabarti, Sarkar, Leelavathamma, & Nataraju, 2005)) and the Biomimicry Card Deck (Volstad & Boks, 2012). More recently Baumeister, Tocke, Dwyer, Ritter, and Benyus (2013) have developed a handbook with a range of BM methods and tools.

Although mimicking nature is an age-old and valid approach in design and innovation, claiming that innovations resulting from mimicking nature are sustainable is misleading (Volstad & Boks, 2012) for isolating a principle, structure or process from nature and imitating it does not necessarily yield to sustainability. As illustrated by Reap, Baumeister, and Bras (2005), this is particularly true for 'reductive' BM, which mimics only forms and processes, while the ecosystem level of BM seems to offer more opportunities (in relation to this see the Systemic Design approach in Section 3.2). In addition, evolution is a mechanism for generating effectiveness, which is valid locally and at system level, rather than perfection. This points to the importance of consideration of context and points to the simplicity of the premise of BM design. BM design isolates problems and uses a technologically-optimistic and product-focused engineering perspective, and although this creates opportunities for radical technological innovation, lacks a transformative potential at the level of production-consumption systems (Gaziulusoy, 2015) and our psycho-cultural patterns (Mathews, 2011).

Biomimicry design example

Lotusan (Sto Ltd) is a self-cleaning facade paint, suitable for masonry and rendered surfaces. Inspired by the observations of self-cleaning properties of lotus leaves, the paint allows water droplets to roll off removing particles of dirt and reducing the build-up of micro-organisms which are common in damp conditions. Lotusan requires a lower maintenance, eliminates the need for harsh chemicals or detergent and has a longer lifespan compared to ordinary paints (Image web link: http://quaderns.coac.net/wp-content/uploads/2014/03/Biomimicry-03.jpg; Additional details: http://www.sto.co.uk).

1.5 Design for the Base of the Pyramid (BoP)

In addition to environmental issues, in the last decade design researchers have started to address social issues, with a particular focus on the Base of the Pyramid (BoP). The BoP is the poorest portion of the global population living with an annual income below a certain Purchasing Power Parity (PPP) threshold (several researchers set it at $2 per day (Karnani, 2011)). In addition to a lack of income to satisfy basic needs, the BoP are characterised by a lack of access to basic services (such as public health, education, sanitation etc.), and by social, cultural and political exclusion (Karnani, 2011; London, 2007).

Prahalad (2004) and Prahalad and Hart (2002) show that the traditional development aid strategy has not been effective in solving the problem of poverty, and they suggest a market-based perspective: companies should look at unexploited business opportunities in low-income markets and treat the poor as consumers and not as victims. In this way companies can realise profit and at the same time bring prosperity by allowing the poor to get access to better and cheaper products and services (Prahalad & Hammond, 2002; Prahalad & Hart, 2002). Two approaches have been proposed (Rangan, Quelch, Herrero, & Barton, 2007): *BoP as Consumer*, where the business focus is on selling products and/or services to those at the base of the pyramid; and *BoP as Producer*, where the business focus is on sourcing products and/or services from those at the base of the pyramid. The claim that poverty can be alleviated by simply targeting the poor as consumers has raised criticisms (e.g. Karnani (2007), Oosterlaken (2008) and Jaiswal (2008)). Among these there is the moral dilemma that the BoP approaches do not differentiate between satisfying essential needs (such as nutrition and health) and offering non-essential goods (Jaiswal, 2008). Even in response to these criticisms, some authors have proposed to move from the first-generation BoP strategy (BoP as Consumer and BoP as Producer) to the second-generation of BoP strategies, which sees the *BoP as business partners* to be empowered, enabled and involved in the process of business co-invention and co-creation (Simanis & Hart, 2008).

Over the past years design researchers have explored the role of Design for the Base of the Pyramid (DfBoP) with a particular focus on developing principles, approaches and tools. An important contribution has come in particular from Delft University of Technology, which started in 2001 a programme of masters degree projects on DfBoP (see for example Kandachar, de Jong, and Diehl (2009)), that constituted the basis for the collection of design cases and elaboration of research outcomes.

As pointed out by Crul and Diehl (2008), even if there is considerable knowledge and know-how in product innovation in industrialised countries, much of this is not directly applicable to low-income contexts. In fact, designing and developing solutions at the BoP requires addressing specific issues that are different from those in high-income markets (Jagtap, Larsson, & Kandachar, 2013; Jagtap, Larsson, Warell, Santhanakrishnan, & Jagtap, 2015). These issues include (Jagtap & Kandachar, 2010; Jagtap et al. 2013): a lack of market information about the BoP (e.g. what the poor need, what capabilities they can offer, etc.); an underdeveloped regulatory environment; inadequate infrastructures (e.g. roads, electricity, water etc.); low literacy and educational levels; and a high barrier to get access to credits. Because of these issues, developing solutions for the BoP requires designers to adopt a different approach to how design requirements are defined and addressed. Gomez Castillo, Diehl, and Brezet (2012) have grouped these requirements into four main interrelated clusters: *desirability* (understanding users, their socio-cultural context, problems, needs and desires); *feasibility* (understanding technological capacity and feasibility) (Kandachar & Halme, 2008; Srinivasa & Sutz, 2008); *viability* (understanding customer affordability) (Anderson & Markides, 2007; Prahalad, 2004; Smith, 2007); and *sustainability* (UNEP, 2006).

After an initial emphasis on product design (e.g. UNEP, 2006; Crul & Diehl, 2008; Oosterlaken, 2008; Viswanathan & Sridharan, 2012), the design research focus on the BoP has moved to Product-Service System (PSS) design (e.g. UNEP, 2009; Moe & Boks, 2010; Schafer, Parks, & Rai, 2011; Jagtap & Larsson, 2013; dos Santos, Sampaio, Giacomini da Silva, & Costa, 2014; Ben Letaifa & Reynoso, 2015; Emili, Ceschin, & Harrison, 2016). By innovating at a business model level (see Section 2), a PSS design approach is considered to offer wider opportunities for addressing the complex set of requirements that characterise BoP projects, and for developing solutions capable to meet the three sustainability dimensions. The assumption is in fact that PSS innovations 'may act as business opportunities to facilitate the process of social-economic development in emerging and low income contexts—by jumping over or by-passing the stage of individual consumption/ownership of mass produced goods—towards a "satisfaction-based" and low-resource intensive advanced service economy' (UNEP, 2002).

More recently scholars have explored the importance of social innovation and social entrepreneurship in the context of BoP (e.g. Bitzer, Hamann, Hall, & Wosu Griffin, 2015; Goyala, Sergib, & Jaiswala, 2015; Michelini, 2012), with a particular emphasis on bottom-up approaches and on an active role for users as co-creators (Chakrabarti & Mason, 2014; Ben Letaifa & Reynoso, 2015). In this context, and from a design perspective, of particular relevance are the 2008 UNEP Creative Communities for Sustainable Lifestyles project (aimed at identifying best practices and making design and policy recommendations on grass root social innovations in low-income countries), and the activities of the Design for Social Innovation for Sustainability network on community-based innovations in informal settlements (e.g. Cipolla, Melo, & Manizini, 2013).

From a methodological perspective, a number of design manuals and tools have been proposed in the past years, providing a set of different and complementary approaches. The most diffused ones are (Gomez Castillo et al. 2012): *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 & Hart, 2008), and the *Market Creation toolbox* (Larsen & Flensborg, 2011), which offer approaches and tools for business model co-creation. A methodological framework integrating the tools provided by these approaches has been proposed by Gomez Castillo et al. (2012).

Design for the Base of the Pyramid example

Delft University of Technology has developed a community-based sanitation system for low-income contexts that processes water on-site and upgrades human waste to energy at an omni-gasification plant. Urine and faeces are dried, converted to syngas and fed into a fuel cell. The gasification process destroys pathogens and generates enough energy to power the system, creating an environmental and economic sustainable cycle (Additional details: http://www.io.tudelft.nl/reinventthetoilet).

2 *Product-service system innovation level*

The design approaches included at the product innovation level are crucial to reduce the environmental impact of products and production processes. However, although they are fundamental and necessary, they are not on their own sufficient to obtain the radical improvements required to achieve sustainability. In fact, even if these innovations can bring about an improvement in products' environmental performance, it is also true that these improvements are often negatively counterbalanced by an increase in consumption levels (Binswanger, 2001; Brookes, 2000; Schmidt-Bleek, 1996). For example, the environmental gain achieved through the improvement of car efficiency in the last 15 years (10%) has been more than offset by the increase in the number of cars on roads and by the related increase (30%) in the overall distance travelled (EEA, 2008). Therefore, product innovation approaches constitute symptomatic solutions which do not go to the root of the sustainability problem (Ehrenfeld, 2008). Thus, there is a need to move from a focus on product improvements-alone, towards a wider approach focused on producing structural changes in the way production and consumption systems are organised.

Within this perspective, several researchers have started to look at Product-Service System (PSS) innovation as a promising approach for sustainability (Evans, Bergendahl, Gregory, & Ryan, 2008; Heiskanen & Jalas, 2000; Mont, 2002; Tischner, Ryan, & Vezzoli, 2009; Tukker, 2004; White, Stoughton, & Feng, 1999; Stahel, 1997; Wong, 2001; Zaring et al. 2001). 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 & Tischner, 2006). In other words PSSs are value propositions oriented to satisfy users through the delivery of functions instead of products (e.g. from selling heating systems to providing thermal comfort services; from selling cars to offering mobility services, etc.). Thus, PSSs entail a shift from a consumption based on ownership to a consumption based on access and sharing.

From an environmental perspective, PSSs can potentially decouple economic value from material and energy consumption (White et al., 1999; Stahel, 1997; Heiskanen & Jalas, 2000; Wong, 2001; Zaring et al., 2001; United Nations Environmental Programme UNEP, 2002; Baines et al., 2007). 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, Jasch, & Sharp, 2004). In addition, PSSs can offer the possibility to find new strategic market opportunities for companies (Goedkoop, van Halen, te Riele, & Rommes, 1999; Mont, 2002; Wise & Baumgartner, 1999), increase competitiveness (Gebauer & Friedli, 2005), establish longer and stronger relationships with customers (UNEP, 2002; Mont, 2004), and build up barriers to entry for potential new competitors (Oliva & Kallenberg, 2003).

Designing PSSs requires a different approach to designing individual products. PSSs are complex artefacts composed of *products*, *services*, and a *network of actors* who produce, deliver and manage the PSS (Dewberry, Cook, Angus, Gottberg, & Longhurst, 2013; Mont, 2002). Designing a PSS requires a systemic approach considering all these elements simultaneously. Various research projects have been funded by the European Union (EU) over the past decade with the aim of exploring PSS innovation and its implication for design.[1] Researchers have initially focused on **PSS design for eco-efficiency**, looking at the economic and environmental dimensions of sustainability (e.g.

Brezet, Bijma, Ehrenfeld, & Silvester, 2001; Manzini, Vezzoli, & Clark, 2001). Several design methods, usually organised around four main phases (analysis, PSS idea generation and selection, PSS concept design and PSS engineering) were developed and tested (e.g. Kathalys, method for sustainable product-service innovation (Luiten, Knot, & van der Horst, 2001); DES, Design of eco-efficient services methodology (Brezet et al. 2001); MEPSS, Methodology for Product-Service System development (Van Halen, Vezzoli, & Wimmer, 2005)). A wide range of tools has been developed in association with these first methods (see Verkuijl, Tischner, & Tukker, 2006): of a particular note are the tools to visualise and communicate PSSs (for an overview see Ceschin, Resta, Vezzoli, and Gaiardelli (2014)), and tools to integrate the environmental dimension in the design process (e.g. the Sustainability Design-Orienting toolkit, www.sdo-lens.polimi.it, developed within the MEPSS project). More recently the attention has moved towards PSS design engineering approaches (for an overview see Cavalieri and Pezzotta (2012)), i.e. the technical and systematic design and development of PSSs (Bullinger, Fahnrich, & Meiren, 2003). In this context, researchers have explored methods for the integrated development of products and services (e.g. Aurich, Fuchs, & Wagenknecht, 2006), methods for modular design of PSSs (e.g. Wang et al., 2011), Computer-Aided Design systems for PSS engineering (e.g. Sakao, Shimomura, Sundin, & Comstock, 2009); methods for building collaborative networks (e.g. Sun, 2010; Zhang, Jiang, Zhu, & Cao, 2012); and methods to be used at more managerial and strategic level (e.g. Bocken, Short, Rana, & Evans, 2013; Yang, Vladimirova, Rana, & Evans, 2014).

In addition to environmental concerns, more recently, researchers have looked at integrating in PSS design also the socio-ethical dimension of sustainability, referring to **PSS design for sustainability** (e.g. Vezzoli, 2007; Vezzoli et al. 2014). Another area where design researchers have been focussing is the application of PSS design in low-income contexts, namely **PSS design for the Bottom of the Pyramid** (BoP) (see Section 1.5).

Although PSSs carry great sustainability potential, they can be difficult to design, test, implement and bring to the mainstream (Ceschin, 2013; Tukker & Tischner, 2006; Vezzoli, Ceschin, Diehl, & Kohtala, 2015): PSSs in fact might challenge existing customers' habits (Catulli, 2012; Mont, 2004), companies' organizations (Mont, 2004; Martinez et al., 2010) and regulative frameworks (Mont & Lindhqvist, 2003). Vezzoli et al. (2015) explored the design challenges to widely implement and diffuse sustainable PSSs, highlighting the following key issues for design research. Firstly, more in-depth studies in user behaviour to better understand what factors influence user satisfaction, as well as how to measure and evaluate this satisfaction (e.g. Mylan, 2015). The role that socio-cultural factors play in user acceptance should also be investigated (e.g. Piscicelli, Cooper, & Fisher, 2015). This knowledge would be valuable to be integrated in existing design approaches and methods. Another priority is to develop a deeper understanding of the process of introduction and diffusion of sustainable PSSs, and how this can be designed, managed and oriented (e.g. see initial studies combining PSS design with transition theories (Ceschin, 2012, 2013, 2014a, 2014b; Joore & Brezet, 2015; Liedtke, Baedeker, Hasselkuß, Rohn, & Grinewitschus, 2015)). Finally, another key area is the understanding the most effective strategies to transfer PSS design knowledge and know-how from research centres and universities to companies and design-ers (see for instance the work by Cook, Bhamra, and Lemon (2006)). Tukker (2015) also highlights the need for more research on experimentation and evaluation of PSS design in practice in different industries.

Sustainable Product-Service System design example

Riversimple is a British company that manufactures a hydrogen-powered car. The car is not sold to customers. Rather, the company retains the ownership and sells mobility as a service. In particular customers can lease the car by paying a monthly fee that covers the use of the car, the maintenance, the insurance and the fuel. This makes the company economically interested in making a car that lasts as long as possible and that is as efficient as possible (Image web link: http://www.riversimple.com/wp-content/uploads/2015/10/how-the-business-works.jpg; Additional details/images: www.riversimple.com).

3 Spatio-social innovation level

3.1 Design for social innovation

To achieve sustainability, there is a need for technological innovations to be complemented by social innovations (Geels, 2005a). The literature on design for sustainability has underacknowledged the complementary nature of these two approaches. This resulted in two separate theoretical and operational streams in design for sustainability, one focussing on technological innovations and the other focussing on social innovations. Literature both on social innovation in general and on design for social innovation specifically has just been emerging in the past decade. Therefore, the discourse is not mature and there are different interpretations and perspectives not only on what social innovation is but also what roles design can play in social innovation processes.

Technological innovations are assumed to be radical, aiming for technological paradigm shifts (Wüstenhagen, Sharma, Starik, & Wuebker, 2008). They generally target environmental problems and, are mainly pulled by governmental policies and pushed by emerging and enabling technologies. Social innovations, either refer to those innovations aiming to solve social problems (Schaltegger & Wagner, 2008) such as poverty and access to safe drinking water, or those targeting behavioural change and social well-being (Manzini, 2007). A more broad and systemic understanding of social innovation defines it as a creative re-combination of existing assets (Manzini, 2014) and avoids a techno-centric framing. Also, in social innovation a key role is played by people and communities. '*Creative communities*' (Meroni, 2007) is in fact an often used term to indicate that social innovations usually emerge from the inventiveness and creativity of ordinary people and communities (sometimes in collaboration with grassroots technicians and entrepreneurs, local institutions and civic society organizations) (Jégou & Manzini, 2008). Examples include self-managed services for the care of children and the elderly; new forms of exchange and mutual help; community car-pooling systems; community gardens; networks linking consumers directly with food producers, etc. (for an overview of social innovation cases see Meroni, 2007).

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 out 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). They can contribute by making them more visible and tangible (e.g. to increase peoples' awareness), more effective and attractive (e.g. to improve the experience of the people involved), and by supporting replication (scaling-out) and connection (scaling-up) (Manzini, 2015). While systemic thinking, alongside more conventional design skills such as visualisation and prototyping are considered as strengths of a design approach in achieving social innovation, criticisms have been raised about the naivete of designers proposing superficial solutions and the high cost of design services (Hillgren, Seravalli, & Emilson, 2011). These are valid criticisms and part of a broader discussion about the changes needed in professional design culture and design education to be able to remain socially relevant in a post-industrial era, a fundamental characteristic of which is intensifying social and environmental crises.

After an initial emphasis on collecting and analysing cases of social innovation (e.g. Meroni, 2007), the focus of design researchers moved towards exploring the role of designers (e.g. Jégou & Manzini, 2008) and the development of social innovation toolkits (e.g. Murray, Caulier-Grice, & Mulgan, 2010). Currently, the focus is mainly on investigating how designers can support and facilitate the process of replication and scaling-up (e.g. Hillgren et al., 2011; Manzini & Rizzo, 2011). In relation to the latter point, it must be acknowledged that approaches solely aiming to generate technological solutions for sustainability problems tend to generate techno-fixes. These techno-fixes target issues in isolation, disregard systemic intervention opportunities, and while seemingly solving a problem at a point in a system, only transferring that problem to another point (i.e. shifting the burden) (Ehrenfeld, 2008). On the other hand, 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.

Design for social innovation example

Circle (Participle) is a membership and mutual support group for anyone over 50 operating at a neighbourhood level. The scheme enables isolated people to find support from other people in the community. For a small subscription all members have access to a free 0800 number for practical support. A small local team responds on demand and connects members to one another (Image web link: https://wearethecityheroes2013.files.wordpress.com/2013/12/sin-tc3adtulo-2.png; Additional details: http://www.participle.net/ageing).

3.2 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. In fact 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 & Fassio, 2011). This approach makes it possible to design/plan the flow of material and energy from one element of the system (e.g. a productive activity) to another, reducing the waste flow by transforming outputs of each system element into an input (opportunity) for another system element (Bistagnino, 2009), potentially resulting in new, locally-based, value chains (Barbero, 2011).

The Systemic Design approach has been applied in several projects focussing on a variety of areas such as agricultural and food networks (e.g. Barbero & Toso, 2010; Ceppa, 2010), industrial processes, water treatment (e.g. Toso & Re, 2014) exhibitions and fairs, and energy systems (e.g. Barbero, 2010). Bistagnino (2009, 2011) provides an extensive description of these and other projects where the approach has been applied. Some tools specifically developed to support designers in Systemic Design project include: a visualisation tool to portray the actors, resources and material & energy flows of a given system (examples can be seen in Bistagnino (2009, 2011) and Barbero and Toso

(2010)); and an IT tool that can organize and match data relative to output (waste), input (resources) and productive activities of a given geographic area (see Ceppa, 2009).

The limitations highlighted for Cradle to Cradle are valid also for Systemic Design. Also, the main problem is that the approach is mainly focused on the production aspects, without addressing the issue of reducing individual consumption. In fact, even if the approach is helpful to design and create local material and energy networks that are more efficient and effective, it does not affect consumer demand of products and services (i.e. it does not change consumption behaviours and habits). For this reason, Systemic Design should be combined with other design approaches (e.g. Product-Service System Design or Design for Social Innovation).

Systemic Design example

Polytechnic of Turin, in collaboration with Lavazza, has implemented a solution to reuse coffee waste as an input for agricultural production. A new productive and value chain was put in place, by which coffee waste can be used in three stages: as a source of lipids and waxes for pharmaceutical production; as a substrate for farming mushrooms; and as a medium to grow worms for vermicompost (Image web link: http://www.dariotoso.it/wp-content/uploads/2014/04/graf1.jpg; Additional details: Barbero & Toso, 2010).

4 Socio-technical system innovation level

While the design profession was in the early phases of engaging with environmental (and later social) issues through frameworks like green design and ecodesign (see Section 1.1), the 1990s saw an emerging focus in the science and technology studies area on transformation of socio-technical systems for sustainability. Early and well-known projects were: the Dutch National Inter-Ministerial Programme for Sustainable Technology Development (STD) (1993–2001); and the European Union funded Strategies towards the Sustainable Household (SusHouse) Project (1998–2000). Both projects were about sustainable need fulfilment with a long-term approach (Quist & Vergragt, 2004, 2006). The former one focused on policy development to influence sustainable innovations (Weaver, Jansen, van Grootveld, van Spiegel, & Vergragt, 2000), and the latter one focused on developing 'Design-Orienting Scenarios' to influence sustainable technological and social innovations (Green & Vergragt, 2002). These projects adopted a 50 year time frame consistent with the time period needed for radical innovations and used a backcasting approach (Weaver et al., 2000). Both of these projects focused not only on influencing technological innovations but also social, institutional and organisational innovations (Vergragt & van Grootveld, 1994; Weaver et al., 2000). Even though these projects focused on different types of innovations in the wider socio-cultural context, the understanding about the formation of these innovations was linear and one-way rather than co-evolutionary and the whole approach was explicitly techno-centric (Gaziulusoy & Boyle, 2008).

Around similar times, as a means to understanding how innovation in socio-technical systems occurs, a group of scholars developed the multi-level perspective of system innovation (MLP) building on evolutionary innovation theory (e.g. Kemp, 1994; Kemp, Rip, & Schot, 2001). Following the early development of the model, MLP was refined and clarified by Geels (2005a, 2005b) and Geels and Schot (2007). The MLP model portrays the dynamic nature of system innovation through a layered structure. There are three levels of the MLP model: socio-technical landscape, socio-technical regime and niche innovations. System innovation is defined as '*a transition from one socio-technical system to another*' (Geels, 2005a: p 2). Building upon these insights, a number of managerial theories and approaches have been developed in the last years with the aim of influencing and steering the direction and pace of transitions. Among these approaches, the most prominent are Strategic Niche Management[2] (Kemp, Schot, & Hoogma, 1998; Schot, 1992) and Transition Management[3] (Rotmans, Kemp, & Van Asselt, 2001; Loorbach, 2007, 2010). Both the earlier projects of STD and SusHouse, and theories developed about system innovations and transitions, created a ground in the design field for cross-fertilisation. A need for more systemic approaches targeting 'cultural change' in the society rather than focussing solely on technological interventions in production-consumption systems were signalled by some scholars as early as in the first half of 1990s (e.g. Ryan, Hosken, & Greene, 1992: p 21). Although recent and emerging, currently there is an observable body of work being developed by a handful of design scholars. As mentioned in Section 3, Ceschin (2012, 2013, 2014a) and Joore (Joore & Brezet, 2015; Joore, 2010) have been exploring connections between PSS design and system innovations and transitions theories (in particular Strategic Niche Management and Transition Management). Gaziulusoy, 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 (Gaziulusoy, 2010; Gaziulusoy & Brezet, 2015). 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, 2015). 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 et al., 2011). Other researchers wrote about '*synergising*' or '*acupunctural planning*' (Jégou, 2011; Meroni, 2008a) and '*urban eco-acupuncture*' (Ryan, 2013a, 2013b) to emphasise the importance of designing a multiplicity of interconnected and diverse experiments to generate changes in large and complex systems (Manzini & Rizzo, 2011). Very recently Baek, Meroni, and Manzini (2015) proposed and tested a framework for a socio-technical approach of designing community resilience. In addition to these, a group of scholars have developed curriculum on what they call as *transition design* for the first time (Irwin, Tonkinwise, & 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.

Design for system innovations and transitions focuses on transformation of socio-technical systems through technological, social, organisational and institutional innovations. In this regard, it embodies design for product-service systems which aims to transform production-consumption systems through business model innovation (see Section 2) and design for social innovation which aims to assist with social change without seeing technological change as a predeterminant of this (see Section 3.1). More recently, design research efforts have started to be focused on cities (e.g. Ryan, 2013a, 2013b; Ryan, Gaziulusoy, McCormick, & Trudgeon, in press), which are essentially systems of socio-technical 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 (for example, see Bettencourt & 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.

Design for system innovations and transitions example

As an emerging research and practice area, the examples of design for system innovations and transitions are still limited. One example is Visions and Pathways 2040 project by the Victorian Eco-innovation Lab in Australia. This project uses design-led visioning to develop desirable propositions for low-carbon and resilient city futures (Ryan et al., in press). This project produced a series of 'glimpses of the future' -snapshots of desirable, low-carbon and resilient futures for Australian cities-across dierent city-system levels including whole cities, precincts and neighbourhoods through participatory processes which were then used to facilitate strategic conversations among stakeholders, in developing four distinct future scenarios and, policy and innovation pathways. Below image shows one of these future glimpses; City of Melbourne in 2040 (Additional details/images: http://www.visionsandpathways.com/research/visions/).

Table 1 Main characteristics of DfS approaches

Product innovation level			
Approach	*Focus*	*Main limitations*	*Potential future research directions*
Green design	Lowering environmental impact through redesigning individual qualities of individual products	- Lacks depth, promotes green consumerism - Focuses predominantly on single-issues therefore does not provide significant environmental gain	- Exploring potential synergies with other approaches
Ecodesign	Lowering environmental impact focussing on the whole life-cycle of products from extraction of raw materials to final disposal	- Lacks complexity, focuses only on environmental problems and disregards problems which cannot be accounted for in life-cycle assessments - 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)	- Exploring potential synergies with other approaches - Developing tools to support decision making at a managerial and strategic level
Emotionally durable design (EDD)	Strengthening and extending in time the emotional attachment between the user and the product	- It is particularly challenging to effectively stimulate product-attachment: the same product can generate different meanings and different degrees of attachment on different individuals - Product attachment determinants are less relevant for some product categories (e.g. utilitarian products) - For some product categories extending longevity beyond a certain point might not be environmentally beneficial - Manufacturers might be averse to implement product attachment strategies because this might lead to reduce sales	- Undertake studies exploring product attachment during the whole lifespan of a product - Test the effectiveness of EDD strategies in different product categories - Investigate the role of culture and user values in product attachment
Design for sustainable behaviour (DfSB)	Making people to adopt a desired sustainable behaviour and abandon an unwanted unsustainable behaviour	- Ethical implications of applying DfSB (who is entitled to drive user behaviour?) - Lack of metrics to measure the effect of DfSB strategies and a lack of evidence based examples - Implementing DfSB might require the use of additional materials and resources - Business stakeholders might not be incentivised in implementing DfSB strategies because this might not be counterbalanced by financial gains	- Development of assessment metrics and techniques for analysing and evaluating of DfSB cases - Test the effectiveness of DfSB strategies - Develop a more accessible language and tools for professionals - Expand the scope of behaviours, contexts and user groups in research - Identifying the most effective DfSB depending on particular situations

(*continued on next page*)

Table 1 (*continued*)

Product innovation level			
Approach	*Focus*	*Main limitations*	*Potential future research directions*
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	- These emphases remain at a rhetorical level and, despite its inspiring vision, CTC design is technically not well justified	- 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	- Claiming that innovation resulting from mimicking nature is sustainable is misleading for isolating a principle, structure or process from nature and imitating it does not necessarily yield to sustainability - Technologically-optimistic	- 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	- 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	- Better explore the application of Product-Service System design and Design for Social Innovation to the BoP

Product-Service System innovation level			
Approach	*Goal*	*Limitations*	*Potential future research directions*
Product-Service System design	*PSS design for eco-efficiency:* design of product-service propositions where the economic and competitive interest of the providers continuously seeks environmentally beneficial new solutions. *PSS design for sustainability:* as above, but integrating also the socio-ethical dimension of sustainability. *PSS design for the Bottom of the Pyramid:* as above, but applied to the BoP.	- Not all PSSs result in environmentally beneficial solutions - PSS changes could generate unwanted environmental rebound effects (e.g. increase in transportation impacts) - 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)	- Better understand what factors influence user satisfaction, as well as how to measure and evaluate this satisfaction - Develop a deeper understanding on the process of introduction and diffusion of sustainable PSSs, and how this can be designed, managed and oriented - Identify effective strategies to transfer PSS design knowledge and know-how from research centres and universities to companies and designers - Experiment and evaluate PSS design in practice in different industries

Table 1 (*continued*)

Spatio-Social innovation level			
Approach	*Goal*	*Limitations*	*Potential future research directions*
Design for Social Innovation	Assisting with conception, development and scaling-up of social innovation	- Criticisms have been raised about the naiveté of designers proposing superficial solutions and high cost of design services - 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 - Develop social innovation toolkits - Research about how to change professional culture and improve design education so that these support social innovation in sophisticated ways.
Systemic Design	Designing locally-based productive systems in which waste from one productive process becomes input to other processes	- The approach is mainly focused on the production aspects, without addressing the issue of reducing individual consumption	- Exploring synergies with other approaches.

Socio-Technical System innovation level			
Approach	*Goal*	*Limitations*	*Potential future research directions*
Design for System Innovations and Transitions	Transformation of socio-technical systems through (strategic) design	- 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

5 Discussion and conclusions

5.1 DfS evolutionary framework

A recent review on sustainability-oriented innovations (Adams, Jeanrenaud, Bessant, Denyer, & Overy, 2016) 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. (2016) 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. (2016) proposed an initial framework to picture how the field of sustainability-oriented innovations has evolved. Our findings indicated alignment with findings of Adams et al. (2016) as we have also observed a shift towards adopting more systemic approaches in the DfS field as well as an increased focus on social issues alongside technological interventions. Due to this alignment between their and our findings, we took inspiration from their analysis model and developed an adaptation of that framework (Figure 1). We then used this new framework to map DfS approaches.

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 were layered on our framework, onto which we positioned the DfS approaches. In particular, the process of positioning the approaches onto the framework was as follows: 1] we ordered the approaches using the Insular/Systemic axis; 2] we then repeated this operation using the Technology/People axis; 3] we then combined the results of the two positioning exercises onto the bi-dimensional framework by drawing, for each approach, an area corresponding to the intersection between the Insular/Systemic and Technology/People coordinates. Each DfS approach is mapped as an area because this allows us to show the overlaps across different innovation levels and between different DfS approaches (a single approach can in fact span over different innovation levels and include other approaches, as for example in the case of ecodesign and green design). A colour code is also used to indicate whether the approach is addressing the environmental dimension of sustainability and/or the socio-ethical one. It is anyhow important to highlight that the process of developing the framework and mapping the approaches has been iterative (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).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.

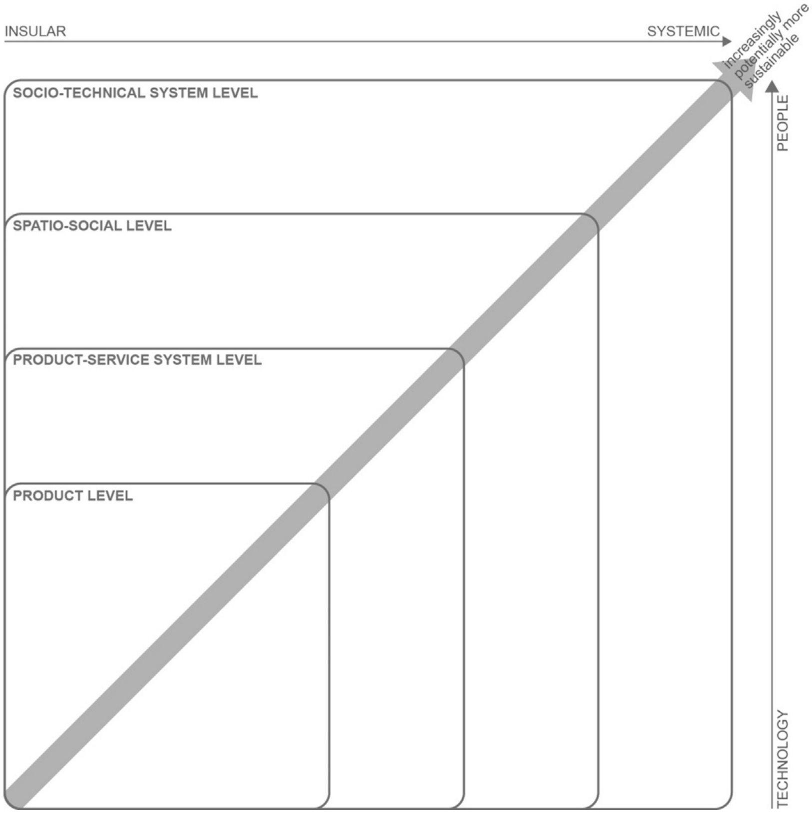

Figure 1 The DfS evolutionary framework

5.2 Reflections and observations emerging from the DfS evolutionary framework

5.2.1 Reflections and observations on the evolution of the DfS field

The DfS field has broadened its theoretical and practical scope over the years displaying a chronological evolution. In the first half of the 90's DfS was primarily 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

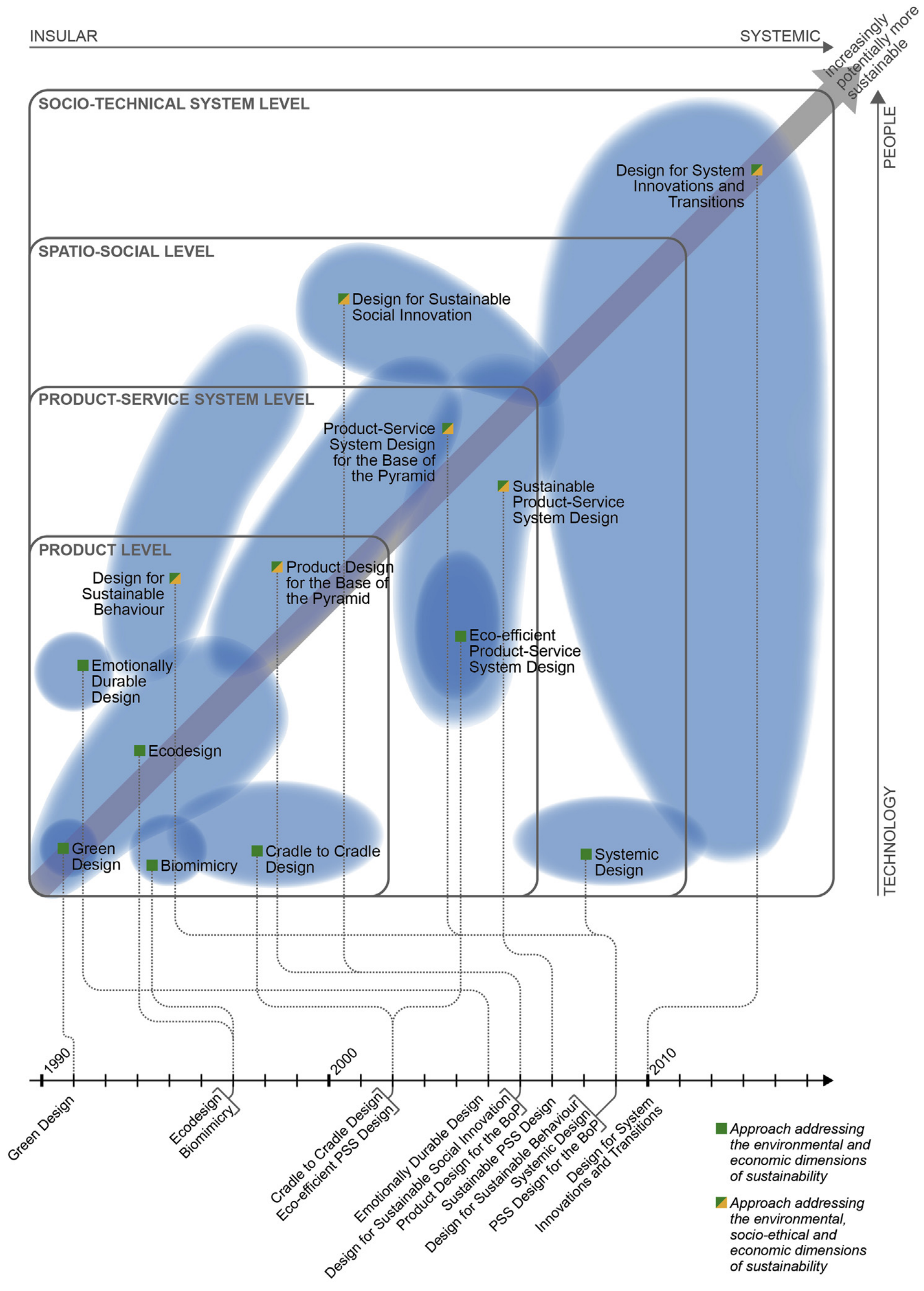

Figure 2 The DfS Evolutionary Framework with the existing DfS approaches mapped onto it. The timeline shows the year when the first key publication of each DfS approach was published

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 focussing predominantly on the technical aspects of sustainability (e.g. see *Green Design*, *Ecodesign*, *Biomimicry, Cradle to Cradle*), the following ones have recognised the crucial importance of the role of users (e.g. see *Emotionally Durable Design*, *Design for Sustainable Behaviour*), resilience of communities (e.g. see *Design for Social Innovation*), and more in general of the various actors and dynamics in socio-technical systems (e.g. see the fourth innovation level).

Similarly, the sustainability focus of the various approaches has gradually 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, democratic empowerment of citizens and in the general quality of life, have been increasingly integrated into the later DfS approaches (e.g. see *Sustainable 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.), and the solutions to these problems 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 network 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 processes 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.

5.2.2 Reflections and observations on the relationships between the various DfS approaches

The framework also offers us the opportunity to reflect on the relationships between the various DfS approaches, and in particular on their linkages, overlaps and complementariness (see Figure 2). To begin with, we must acknowledge that not all approaches are mutually exclusive, in fact, only in a few of them such clear distinction can be observed (e.g. *Emotionally Durable Design* and *Systemic Design* have a completely different focus and no point of contact). In general the approaches we discussed 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 product life cycle stages and processes; 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.

At this stage, it is also interesting to discuss the relationship between the DfS approaches and the concept of Circular Economy (CE), which is considered as a potential solution to foster environmental protection without limiting economic growth (Lieder & Rashid, 2016; Stahel, 2016). CE can be defined as 'an industrial economy that is restorative or regenerative by intention and design' (Ellen McArthur Foundation, 2013). At the core of the concept there are the so called 3R principles (reduction of resources, reuse and recycling), and the realization of a closed loop system of material flows (Geng &

Doberstein, 2008) with the aim of reducing the material and energy resources that enter a production systems and minimising waste (Lieder & Rashid, 2016). In this sense, although it has been popularised and branded by Dame Ellen MacArthur as 'circular economy', the principles have been around for a long time. CE can be seen as an 'umbrella' concept that encompasses various principles (i.e. industrial ecology, biomimicry, cradle-to-cradle) and strengths and weaknesses of these approaches are also valid for CE.

In relation to design, it appears that various DfS approaches are crucial in the process of implementing CE solutions: Cradle-to-Cradle Design and Biomimicry Design can provide support to selecting materials and designing products that foster closed loop material flows. Ecodesign can offer a broader approach on the whole product life cycle and can enable the integration of the 3R principles in product design, with an emphasis on both material and energy flows. Systemic Design can be used to design products and industrial systems based on industrial ecology principles. Product-Service System design can be instrumental to design business models that enable and foster CE (e.g. see Tukker, 2015; Stahel, 2016). Finally, design for system innovations and transitions can propose alternative forms of CE for new socio-technical system scenarios underlied by a variety of political-economic assumptions, thus, problematising the neoliberal foundations of CE and assisting in its theoretical reframing with implications on practice.

Overall, even if all DfS can contribute to CE in different ways, so far the notion of CE has referred primarily to the most technically-focused DfS approaches (covering various innovation levels from materials to products, business models and industrial systems), with a limited emphasis on user practices and behaviours (and thus on approaches like Design for Social Innovation, Emotionally Durable Design and Design for Sustainable Behaviour).

5.2.3 Reflections and observations on the importance of each DfS approach

According to our current understanding sustainability is a challenge to be addressed at a socio-technical system level. However, this does not mean that those DfS approaches that are less systemic are less important than others. It is true that the approaches at the lower level (the ones focussing on product innovation) cannot alone be sufficient to achieve sustainability, but it would be a mistake to consider these approaches less useful. For example, Product-Service System innovations and community-based innovations require material artefacts that need to be properly designed. This means that 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 its associated strengths and shortcomings, and should be utilised in conjunction with complementary 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 the 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 and linking these visions to activities and strategic decisions of design and innovation teams. Achieving these visions will require design and innovation teams to use a combination of the approaches in lower levels and use in development of new technologies, products and services (Level 1), new business models (Level 2), new social practices (Level 3) that can be part of the envisioned future systems.

5.2.4 Reflections and observations on the knowledge and know-how related to each DfS approach

Finally, some considerations can be made about the different sets of skills required by the practitioners in implementing the various DfS approaches. Earlier we highlighted 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 (for an overview on human-centred design see Giacomin (2014)). 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 DfS approaches, such as *Emotionally Durable Design and Design for Sustainable Behaviour*, require designers to be provided with a different set of expertise. In particular human-centred design skills become crucial. 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's 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 the co-design process is essential (to this respect Meroni introduced the concept of community-centred design (Meroni, 2008a)).

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 means that designers must be capable of: a] addressing 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, 2008b; Vezzoli, 2007); b] creating clear, comprehensible and shared visions to orient innovations (Borja de Mozota, 1990); c] contributing to create relations between a variety of stakeholders of a value constellation (Zurlo, 1999); and d] acting as facilitator to stimulate a strategic dialogue and co-design processes (Meroni, 2008b). This is also true for the Spatio-social level (for example, in relation to *Design for social innovation* see Meroni (2008b) and Sangiorgi (2011)), and becomes even more crucial when operating at a socio-technical system level (Ceschin, 2014a).

5.3 Concluding remarks

This paper contributes to design theory in general and the DfS field specifically by providing an overview of the historical evolution of responses to sustainability problems in the design profession, and by proposing a framework that synthesizes the evolution of the DfS field. The framework shows how the DfS field has progressively expanded from a technical and product-centric focus towards a focus on 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.

From an academic point of view, to our knowledge this is the first time that a framework embracing all the DfS approaches has been developed, providing a synthesis of the DfS field. In this respect the framework contributes to the DfS discourse and is meant to engage and trigger design academics and researchers in the discussion on how DfS has evolved in the past decades and how it is currently evolving.

From an education point of view the framework might be useful in design courses to communicate to students the richness and complexity of the DfS field, and to explain how individual DfS approaches contribute to different aspects of sustainability. The framework might also be used by teachers as a supporting tool to design courses and programmes on DfS (e.g. by mapping out the approaches to be taught in the different levels of a programme).

Finally, from a design practice perspective, the framework might be used by practitioners and organisations to navigate the complex DfS landscape, or to identify the appropriate approaches to be adopted in relation to specific sustainability challenges. Ideally, the framework might also be used as a tool to support organisational change in organisations that aim to integrate DfS in their strategy and processes.

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Notes

1. *ProSecCo*, Product-Service Co-design (EU funded, 2002–2004), *HiCS*, Highly Customerized Solutions (EU funded, 2001–2004) (see Manzini, Collina, & Evans, 2004), *MEPSS*, MEthodology for Product-Service System development (EU funded, 2002–2005) (see van Halen et al. 2005), *SusProNet* Sustainable Product-Service co-design Network (EU funded, 2002–2005) (see Tukker & Tischner, 2006), and LeNS, the Learning Network on Sustainability (EU funded, 2007–2010) (see Vezzoli & Ceschin, 2011).
2. Strategic niche management (SNM) is a managerial perspective rooted in quasi-evolutionary thinking on technological change as well as social constructivist approaches for technology assessment (Kemp et al., 1998; Schot, 1992). Its core idea is that experimental projects (such as pilot- and demonstration projects) in partially protected spaces (niches) have a high potential to stimulate the introduction and diffusion of radical new technologies.
3. Transition Management (TM) is a form of reflexive governance for managing transitions to sustainability combining long-term envisioning with short-term action and reflection7 (Rotmans et al. 2001; Loorbach, 2007, 2010). This instrumental approach has materialised in a substantial number of projects concerned with influencing national, regional and city-level governance processes (Loorbach, 2007).

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