Chapter 15
Eco-Design and Sustainable Development: A Speculation About the Need for New Tools and Knowledge

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Abstract Many outputs of the application of eco-design principles and guidelines result in solutions that slightly differ from previous ones. Although the environmental advantages of new solutions are evident, the extent of achieved benefits fails to pursue the objectives of sustainable development. The latter requires disruptive change and the contextual demise of old generations of products with worse environmental performance. This is made possible just when environmental friendly product transformations positively capture the social and the economic dimension too, as these are accompanied by changes in people's habits and fueled by customer satisfaction. However, few enterprises are available to engage in radical innovation, as it is generally understood as a risky endeavor. The situation is made more complicated by the relatively poor availability of design methods that target radical product redesign. Proactive design methods and thinking strategies are commonly in play when substantial design changes are expected, but no standard methodological reference has been established so far. Based on theoretical reflections and literature evidence, the paper outlines the need for new knowledge, as the foundation of new methodological frameworks to enable the design of products whose environmental, social, and economic sustainability is ensured.

15.1 Context of the Research

Many eco-design methods focus on the reduction of the environmental impact across the product life cycle, but this does not always result in ipso facto in an effective capability of driving design toward sustainable development. The latter can be defined as the "development that meets the needs of the present without compromising the abil-

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ity of future generation to meet their own needs" according to the World Commission on Environment and Development.

One of the causes can be identified in the disregard of human behavior and social issues demonstrated by many eco-design methods [1]. For instance, eco-design offers several design strategies to extend product life span. For some products, extending longevity beyond a certain point might not be environmentally beneficial [2]. Moreover, for some product categories, the end of the life span is not caused by technical issues, but it is more likely due to psychological obsolescence, i.e., a product is discarded because of changes in users' perceived needs, desire for social status emulation or new trends in fashion and style [3, 4]. This calls into question, among others, effective and value-related aspects of green products. The growing awareness that the interaction of consumers with products heavily affects the environmental impact has led to the development of design for sustainable behavior. Although studies that aim to drive user behavior may have positive effects in the sustainability field, there is a concern regarding the extent to which designers and companies are entitled to drive user behavior [5].

In order to make the innovation of eco-designed products more systemic, the literature stresses the importance to innovate business models through the creation of new paradigms aiming to revolutionize the economic context by leveraging eco-design rules contextually [6–10]. Sustainability can be seen as a driver for innovation itself, as demonstrated by a number of new entrepreneurial initiatives and sustainability-fostering policies undertaken by well-established companies [11–15]. Here, the concept of sustainability is also implicitly linked with the capability of achieving success, especially if social and economic aspects are considered beyond the environmental ones. For instance, to support this process, principles that address to servitization include indications for transformations in the ecological and economic senses. It is worth noting that the economic sphere cannot be neglected in this context, as market success of eco-designed products is the key to the demise of old product generations. Indeed, success allows the benefits of more environmental friendly products to be enjoyed, which is an enabler of sustainable development. At the same time, the need to produce a considerable level of changes makes the objective of coming up with radical innovation apparent when sustainable development goals are in play.

On the one hand, in order for success to be achieved, it is fundamental to carry out the early design phases carefully. All design objectives have to be selected and clarified adequately from the beginning of design tasks. This applies to sustainability objectives, besides all the other product performances, which have to be considered already in the Fuzzy front end (FFE). On the other hand, radical innovation can take place just when the FFE is carefully carried out in the design process.

To this respect, it seemingly emerges that the framework for designing products while pursuing sustainable objectives is consistent, as attention to the early design phases could be considered as the key to sustainable development. The sections that follow (2 and 3) indicate that this process is not straightforward, that methodological guidance is inadequate, and that a general consensus on the forms of innovation necessary for sustainable innovation has not been completely reached either. Section 15.4 builds on the evidence and outlines possible ways to support the design of products

whose goals mirror the objectives of sustainable development. The paper ends with some comments to the surveyed literature, gaps in the creation of new design tools and the authors' research agenda in the field (Sect. 15.5).

15.2 Sustainability and Radical Innovation

While bearing in mind the growing population and the growing demand of the emerging and developing countries, the sustainable requirements would be effective only if eco-efficiency decoupled [16]. This means that no partial modification, no incremental innovation of employed technologies, and no re-designing of the existing systems can ensure sustainable development [2]. This supports the importance of radical innovations, not just at the technological level, but also at the cultural level.

The design approaches employed in product innovation are crucial to reduce the environmental impact of products and production processes. However, although they are fundamental and necessary, they are not sufficient to obtain the radical improvements required to achieve sustainability. Indeed, even if these innovations can bring about improvements in products' environmental performance, it is also true that these enhancements are often counterbalanced by increasing consumption [17, 18]. 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 traveled" [1, 19]. Thus, there is a need to move from a specific focus on product improvements toward a holistic approach to structural changes in the way production and consumption systems are organized.

The above evidence supports the need to embrace radical innovation strategies for sustainable product development, which is prevalent in the literature [20–22]. However, sustainability-oriented innovation is inherently featured by both radical and incremental moves [23]—just their suitability to the scope might differ. Szekely and Strebel [24] individuate even more nuances of these kinds of innovation ascribable to sustainable targets. Both radical and incremental innovations are required according to [25], who illustrate the factors that favor the two. Smaller companies, thanks to their flexibility, have more chances to give rise to disruptive innovation in the sustainability context [26]. Eventually, more articulated studies individuate the social dimension as a key to radically innovative sustainability solutions, which, on the other hand, might be of limited profitability [27].

15.3 The Articulation of the Fuzzy Front End and the Triggers for an Effective Sustainable Design

The change requested is achievable just if we put into question the design choices that underlie the current products. In order to explain how design choices affect the product's innovation-level in a new product development (NPD) process, it is essential to present the schematization of the design process introduced in [28]. The designers' task is to design products (and services) in order to satisfy the needs, requirements, and expectations of human beings [29]. Therefore, the objectives of the designer include the translation of human needs into technical solutions. Hence, it is possible to assert that the design process begins with the acquisition of abstract design inputs, where consumer needs are described, and it ends (at least in its first comprehensive iteration) with the realization of the project documentation which allows a company to start the production phase.

Making once again reference to sustainability issues, Vezzoli and Manzini [2] highlight how greater effectiveness in terms of sustainable innovation is achieved by acting on early design phases, i.e., product planning (PP) and conceptual design (CD), which constitute the FFE. Indeed, no innovation in later phases allows designers to achieve the requested sustainability objectives. The ability to deal with objectives in abstract terms during the FFE prevents designers from focusing on existing solutions. New solutions are explored, which enables enhancements in designers' creativity and increased capability to propose innovative ideas.

Although it is essential to intervene in the FFE, it is appropriate to distinguish between potential innovations coming from PP or CD, whose outputs are the problem definition and the conceptual problem solution, respectively. In the first case, defining the right problem is seen as the most critical factor for achieving success. In the second case, solving the problem defined in the PP in a creative way allows the fulfilment of the FFE objectives, but, if the problem defined in the PP is not viable to drive toward successful development, any efforts made in CD (and in the subsequent detail phases) will result useless in this sense.

In addition, it is claimed that the key to achieve business goals is to be more effective and efficient than competitors in identifying and satisfying the needs of target markets [30], by developing and delivering products and services that are valued by customers [31, 32]. To this respect, two main categories of PP approaches are defined in the literature, namely responsive and proactive methodologies [33]. While the former aim to unveil customer preferences and use them as fundamental competing factors, the latter focus on industry exploration in order to individuate differentiation opportunities.

Responsive approaches reduce the level of uncertainty related to the market response toward new product ideas [34, 35] but do not support the exploration of new features and market contexts. Not surprisingly, many authors [36, 37] have argued that customers are not able to conceive the benefits of radically innovative products. Therefore, anticipating what customers will value cannot be achieved just by becoming familiar with their preferences, experiences, and clearly defined expectations.

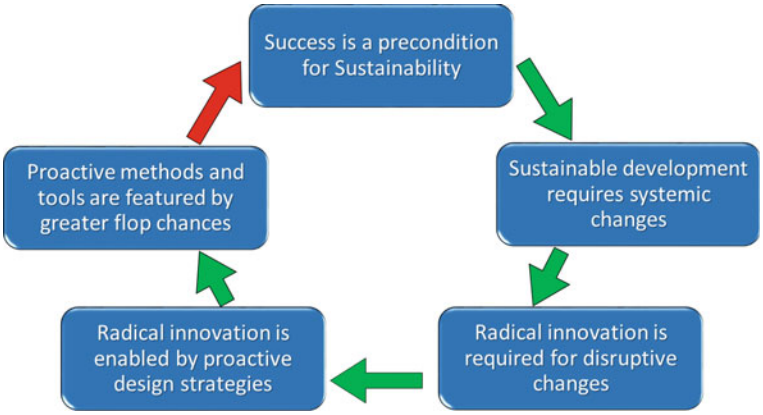

Fig. 15.1 Extant conflict (featured by the red arrow) in the strategy for designing products aligned with the goal of sustainable development

Proactive strategies in the NPD boost the chances of developing successful innovations [38]. However, it is shown that proactive approaches might guide the designer toward product ideas that result too distant from customer expectations [39]. Reid and De Brentani [40] claim that these kind of strategies, as opposed to responsive methodologies, are quite complex and produce (potentially) radical innovations whose market results are considerably uncertain. Many scholars claim that radical changes, driven by proactive strategies, are likely to lead to failure or are, at least, featured by high unpredictability of market results [40, 41]. Consequently, a dichotomy is to be faced: while the pursuance of sustainable objectives calls for radical innovation, this might give rise to flops, which, in turn, conflict with the initial (sustainability) goals, as illustrated in Fig. 15.1.

Not surprisingly, the necessity to both innovate in a radical way and ensure the development of a successful product triggered the creation of hybrid tools, identified from Bacciotti et al. [33], in which customers play very diverse roles.

15.4 Tools and Requirements for Radically Innovative Sustainable Design: Inferable New Areas of Knowledge to Explore

While social aspects are attributed to major interest, also because overlooked so far, integrating radical changes in a social context is an ambitious challenge. Design knowledge might be insufficient to pursue the scope of unfolding social benefits through developed products. The design goal should be at least extended to the development of products/services or systems capable of delivering value for all the stakeholders that interact with the new design during its whole life cycle. As high-

lighted in the introduction, many eco-design methods are unsuitable for addressing the ideation of benefits product design should deliver because they address strategies in order to limit environmental damage rather than promoting new value propositions. At the same time, general-purpose idea generation tools do not usually show any specific preference for sustainable aspects [42], as their overall purpose is the identification of unexplored market opportunities irrespective of the value drivers they exploit.

Given the shifted shortcomings of eco-design and idea generation approaches, a valuable goal is represented by the development of tools that are capable of both focusing on sustainability issues and stimulating value-adding creativity. To the scope, it is necessary to shed light on the actual mutual relationships between value innovation and sustainability. This kind of interplay is argued in the literature and, as a consequence, the way to overcome possible conflicts has been designed. At the present stage, a first research issue is represented by the need to provide a major understanding of this subject.

Then, the distinction between sustainable and unsustainable products is a tough (and rather imprecise) task if the broad technological, social, and evolutionary contexts are not defined. Products existing nowadays and considered sustainable can be seen as the expression of designers, whose endeavor was not limited to considering sustainability but has rather tried to include value dimensions. Indeed, these "win-win" products have thrived by fulfilling stakeholders' needs beyond taking sustainability into account. As mentioned, products that were just oriented on environmental friendliness and that have showed limited consumption levels have resulted in useless production cycles and have become rapidly obsolescent. On the other hand, the characteristics of the recalled win-win products should be studied advantageously. With an empirical approach, suggestions might arise from a study activity that aims at elucidating common features or principles of successful and sustainable products. Many proactive strategies have been developed according to heuristic approaches based on specific taxonomies, which, subsequently, are proposed to designers in order to repeat similar analogical patterns. For instance, we can mention the Blue Ocean Strategy [31], the Design Heuristics [43], and iDea [44]. Hence, a specific taxonomy could be created from scratch to describe successful (unsuccessful) and, at the same time, sustainable products. Principles and invariants included in the existing taxonomies might be likely combined and/or integrated.

Moreover, it is necessary to understand the perception of sustainability according to different perspectives. In a certain sense, limiting the perspective to designers or consumers would give rise to the same dichotomy that was pointed out with regard to proactive and responsive methods. Indeed, accounting only designers' viewpoint would recreate those conditions that lead to purely proactive development. On the other hand, the sole consideration of the stakeholders' requirements would likely drive to responsive and incremental innovation, which, as already mentioned, does not guarantee the kind of the development requested to face the huge sustainability challenges. To this respect, the mentioned hybrid methods (at least the most traditional ones) have not succeeded in both achieving radical innovation and minimizing uncertainties with respect to future success outcomes [45] and no standard

methodology has emerged as well. In other terms, the consideration of a multi-faceted perspective on value and sustainability might allow the highlighting of those dichotomies to overcome in a more evolved design strategy. It is worth noting that the relationship between the capability to deliver value and sustainability can be considered as a specific aspect of the conflict between environmental friendliness and profitability. As achievable, e.g., from a case study presented in [46], strictly following the principles of sustainability can lead to a worsening of some general performance and to the decrease of value perception enjoyed by some stakeholders. According to [47], trying to develop a product that overlooks customer requirements for increasing environmental benefits is counterproductive. On the other hand, the environmental consequence of mass manufacturing and mass consumption has led to social and institutional awareness regarding the need to pursue sustainable development. Thus, stakeholders perceive product sustainability as a source of value per se [47].

15.5 Implications, Final Remarks, and Future Work

The present paper has presented a number of issues, supported by literature sources that constitute hurdles to the fine-tuning of design tools that target sustainable development. Different views emerging in the literature lead to a series of conflicts, which have to be overcome in order to enable the development of appropriate (eco-) design instruments. The authors report here the main points that have arisen in the analyzed literature.

- Although radical innovation is thought as a necessary vehicle to sustainable development, forms of incremental sustainability-oriented innovation are the most diffused (and should be fostered as well).
- Radical innovation is generally achieved by means of proactive design strategies, which are featured by significant risks; on their turn, diminished success chances contradict sustainability objectives, as the latter require that commercial failures are avoided.
- While economic aspects are diffusely taken into account (at least the objective of customer satisfaction is normally considered), the social aspects are not well integrated into eco-design. This happens although sustainable development requires systemic changes that should affect the social sphere.
- At the design level, the shifted pros and cons of responsive and proactive methods for the product planning are recognized. No established methodology can claim to have solved this dichotomy and, while this conflict affects engineering design in general, it impacts on sustainable-oriented design and innovation even more severely.

Section 15.4 has already highlighted some research issues emerged by considering the above problems altogether. According to the authors' view, these issues cannot be tackled with the present level of available knowledge and they have individuated

the relationship between sustainability and value as the most critical aspect to be clarified. The clarification of this relationship can take place at the individual level, as value is properly defined at that scale, or at the social level, if success is considered as the manifestation of collective value, which justifies positive economic outputs or large repercussion on the society itself.

Consistently with this key of reading, the authors are intentioned to undergo studies aimed at the following objectives.

- The analysis of determinants or invariants found in eco-designed products that have achieved success in the marketplace.
- The individuation of successful eco-design tools, which can be revealed, e.g., by the set of eco-design principles that have proven to favor market success.
- The understanding of the shift in value perception of eco-designed products with respect to more common and less environmentally friendly product versions. Here, the concept of value has to be holistically considered, by addressing both its utilitarian (conscious) and hedonistic (unconscious) dimensions. A first step in this direction has been made in [48].
- The capability of design tools that push toward non-trivial product changes to support the shift of eco-design toward an adequate level of innovation for sustainable development. In this context, the research group will benefit from previous exposure into TRIZ, with a particular reference to instruments capable of providing holistic views of the problems [49] and proven combinations with other design methods [50].

All these studies can be firstly treasured in guidelines that support designers in sustainability-oriented innovation. The guidelines should be capable of anticipating the outcomes of sustainability-oriented moves or eco-design principles in terms of not just environmental benefits, but also potential value repercussions and linked success chances.

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