From EcoDesign to Industrial Metabolism: Redefinition of Sustainable Innovation and Competitive Sustainability

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Abstract. Successful enterprises are distinguished by their sustainable development reliant on their ability to learn and develop innovative solutions. Recyclability (material and product design) and recycling (process design) emerge as new paradigm for sustainable competitiveness.

The paper makes a critical evaluation of the most commonly tools and techniques in use and suggests a redefinition of the concept of EcoDesign by integrating End-of-Life activities to gain industrial metabolism. This approach takes a broader innovation perspective, necessary to construct a sustainable innovation community with material balance of the system. The paper suggests a modular approach as generator for integrating embedded firm specific elements into a renewal networked supply chain.

Keywords: Sustainable innovation, Radical change, EcoDesign, Industrial metabolism, Modularity.

1 Introduction

It was Schumpeter [7] who first describes the dynamic pattern in which innovative firms unseat established firms through an innovation process he called “creative destruction” an insisted that disequilibrium was the driven force of capitalism. In significant hostile competitive environments forced by dramatic changes in technological and economic global infrastructures, firms are seeking new competitive edges. Since Taylor’s [9] seminal work, the global engineering community has produced endless methodologies with the focus on operational efficiencies to gain cost advantages. But these advantages run out of competitiveness because firms are similar in their exploitation of methodologies advancing incremental improvement only in products, processes, and services. The increasing global hostile battlefield on cost advantages has recently been enlarged by incumbent firms desperately seeking profit opportunities by moving their cost curve from established market to developing markets such as China, India and similar.

But there is not much new dynamic innovation as business driver by pulling existence production technologies to emergent markets to gain continuous improvement of exiting products and processes based on lower cost of wages, materials, manufacturing, maintenance etc. The key to survival are founded in capitalizing on the

V. Prabhu, M. Taisch, and D. Kiritsis (Eds.): APMS 2013, Part I, IFIP AICT 414, pp. 111–118, 2013.

changing nature of market. Those managers, who are able to perceive trends and weak signals where others see only noise or chaos, that reposition their firms proactively and change the way, they think about products, technologies, processes and business models, will develop competencies to survival funded on innovative competiveness that rivals will be hard-pressed to match.

The ongoing process of creative destruction of the economic structure, from price competition to dynamic innovation founded on new competences in knowledge, innovation, and learning as core aspects within a global structured network of actors, networks and institutions, transforms dramatically the socioeconomic landscape. Further, an era of abundant raw materials, cheap energy, and limitless sinks for waste disposal is running out, making increase pressure from legislators, customers and networks to improve environmental performance.

To improve environmental performance foresight managers must focus on reducing the life cycle impacts of products through technological innovation and outdate practices and technologies from the price competition era.

The paper is conceptual attempting to evaluate from a critical stance common approaches applied to gain sustainable innovation. It serves the purpose to identify critical parts as driver of competitive sustainability and of providing a holistic approach on sustainability. The rest of this paper is organized around three key questions: (a) Is EcoDesign a driving force to radical change (b) Is Cradle-to-cradle a driving force to radical change (c) and how can a generator be constructed to gain industrial metabolism.

2 The Battle of Innovation Approach

Weizsaecker [11] reported that global waste account on more than half of the world's GNP and much of this is from inefficiency in design. It is an enormous challenge for society to change this waste disaster which has taking the rise in firms reactively respond to ecological environment.

Most managers, especially in operations, focus on the constraint that environmental regulation imposes on product and or process designs. The traditional approach to product design is that materials, assembly, and distribution cost are minimized instead of optimizing life-cycle performance which includes maintenance, reuse, and disposal issues.

Sustainability is a systemic concept which derives from understanding the entire cycle of products, from raw material extraction to final disposition. Figure 1 illustrates a typical material product life cycle and shows some alternatives at its end-of-life phase [5]. The main flow (product life cycle) is composed of the following phases: raw material extraction, primary industry, manufacturing, usage and product discarding at its end-of-life. The secondary flow is related to the different end-of-life strategies: reuse, remanufacturing and recycling.

EcoDesign can be seen by systematic integration of creativity, innovation and environmental responsibility into the design process across the product life cycle from cradle to grave (industrial eco innovation). McDonough [4] argue for a fundamental conceptual shift away from current industrial system designs toward a “cradle-to-cradle” system which design industrial systems to be commercially productive, socially beneficial, and ecologically intelligent (industrial metabolism innovation).

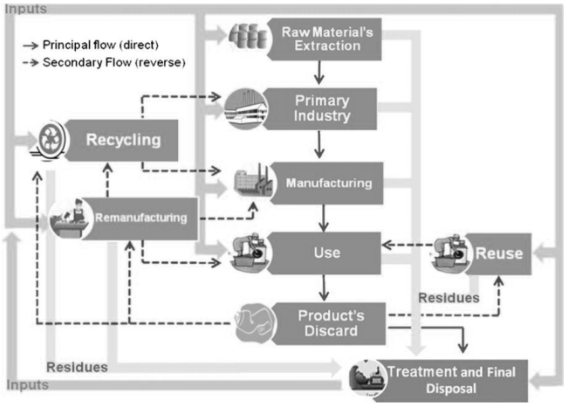

Fig. 1. Material product life cycle [5]

Metabolism innovation and eco-innovation coves the spectrum of levels of innovation from incremental to radical. Stevels [8] advocates four main levels of innovation:

1. Level (incremental): Incremental or small, progressive improvement to existing products.
2. Level (re-design or green limits): Major re-design of existing products but limited the level of improvement that is technically feasible).
3. Level (functional or product alternatives): New products or service concepts to satisfy the same functional need e.g. teleconferencing as an alternative to travel.
4. Level (systems): Design for sustainable society.

In the following section these two innovation approaches are outlined, and their ability as driving force to radically change the innovation process from an efficiency focus into to an effectiveness focus is evaluated.

2.1 EcoDesign as Driving Force to Radical Change

Today, nearly all processes and approaches related to the integration of environmental considerations in product design are grouped under the term EcoDesign. The most common approach used for EcoDesign is life-cycle analysis (LCA). It involves taking simultaneously into account the environmental impacts in the selection of raw materials, the manufacturing, the manufacturing process, the storage and transportation phase, usage, and final disposal and van Hemel [10] include proper recycling. The aim is to find a new way for developing products where the environmental aspects are given the same status as functionality, durability, cost, time-to-market, aesthetic, ergonomics and quality [5].

Hill [2] proposes that the following self-evident EcoDesign axioms should be considered and reduced at all stages along the product life cycle: manufacture without producing hazardous waste; use clean technologies; reduce product chemical emissions; reduce product energy consumption; use non-hazardous recyclable materials; use recycled materials and reused component; design for ease of disassembly; product reuse or recycling at the end of life.

These axioms only adds environmental considerations to product design but do not incorporate more innovative practices, employ ecological principles, and encompass social and ethical aspects.

Knight [3], made a bibliographic review of current published material on EcoDesign tools, techniques and case studies and categorized those in three broad groups:

1. Guidelines: defined as: providing broad support, with little detail, but applicable either across the whole product development process and lifecycle, e.g. ISO/TR 14062, or covering a significant area, e.g. design for recycling; design for disassembly; design for lifetime optimization.
2. Checklists: defined as: providing in-depth, but narrow application at selected stages of the product development process or lifecycle.
3. Analytical tools: Defined as: providing detailed and/or systematic analysis at specific stages of either the product development process or lifecycle e.g. eco-indicators; environmental effect analysis; environmental impact assessment; life cycle assessment; material, energy and toxicity matrix; life cycle cost analysis.

The range of tools and techniques applicable and in use seems to be linked to level 1 and level 2 in the innovation process, whereas when the challenge is systematic integration of creativity, innovation and environmental responsibility into new product concepts and productions systems application of LCA is becoming too complicated.

Based on literature analysis and current EcoDesign experiences van Hemel [10] clustered 33 EcoDesign principles, possible solutions to improve the environmental profile of a product system, taking all the stages of its life cycle into consideration, into eight EcoDesign strategies illustrated in Table 1. He clustered the strategies into two: the ‘evolutionary’ approach; and the ‘revolutionary’ approach. The incremental approach deals with a straightforward process of incorporating environmental principles into the design process while been largely technological focused. The innovative approach aims to develop new products, services and scenarios that enhance sustainable Lifestyles. Van Hemel [10] investigated 77 Dutch SME’s use of EcoDesign principles for improving the environmental profile of products and concluded that all of these were incremental with a clear technological focus.

Schischke [7] found in their investigation of EcoDesign in SME operating in the electrical and electronic sector that these firms rarely implement EcoDesign in the product development process. Stevels [8] argue that EcoDesign is in a situation in which there is a kind of “saturation”, enhanced by increasing legislation, easy technical improvements have been realized, limiting the potential of further competitiveness, and ‘green’ has turned out to be part of total functionality value. Bhamra [1] concludes in his investigation of EcoDesign models that little is understood or practiced with most EcoDesign theory because it is incremental in nature.

Table 1. EcoDesign strategies and principles [10]

EcoDesign strategies	EcoDesign principles
1. Selection of low-impact materials	Clean materials, Renewable content materials, Recycled materials
2. Reduction of materials usage	Reduction in weight, Reduction in volume
3. Optimization of production techniques	Clean production techniques, Fewer production steps, Low/clean energy consumption, Less production waste, Few/clean production consumables
4. Optimization of distribution system	Less/clean reusable packaging, Energy-efficient transport mode, Energy-efficient logistics
5. Reduction of impact during use	Low energy consumption, Clean energy source, Few consumables need, Clean consumables, No waste of energy/consumables
6. Optimization of initial lifetime	High reliability and durability, Easy maintenance and repair, Modular/adaptable product structure, Classic Design, Strong product-user relation
7. Optimization of end of life	Reuse of product, Remanufacture/refurbishment, Recycling of materials, Safe incineration (with energy recovery), Safe disposal of product remains
8. New concept development	Shift to service provision, Shared product use, Integration of functions, Functional optimization

2.2 Cradle-to-Cradle as Driving Force to Radical Change

Design for sustainable society (Level 4 of innovation) demand optimizing life-cycle performance, re-designing products and services based on re-thinking and new thinking with connection to life style change. This concept proposes the transformation of products and their associated material flows such that they form a supportive relationship with ecological systems and future economic growth The goal is not to minimize the cradle-to-grave linear material flow, but to generate closed-loop cyclical industrial systems that turn materials into two distinct metabolisms: the biological metabolism and the technical metabolism.

Three tools or instruments of industrial metabolism are most commonly applied. Ecological footprint; environmental life cycle assessment; and industrial ecosystems. The ecological footprint is a physical material and energy flow measure to and from a specific economy (country, region, land). Life cycle assessment has become the most widely used tool of practical environmental policy and industrial management. The cradle-to-cradle approach is an industrial ecosystem that alerts policy makers and managers to the importance of integration production, consumption and recycling activities and processes into a one local system.

On the firm level the cradle-to-cradle approach has growing attention in both industry and academics. It is claimed to be a science and value based vision of industrial systems to be commercially productive, socially beneficial, and ecologically intelligent [4]. Based on the 12 Principles of Green Engineering, designers and engineers can optimize products, processes, and systems.The principles are visionary guidelines to designer of industrial systems and not a defined conceptual approach including practical applications and tools. The focus is almost entirely on the physical flows of matter and energy in both the Product-Life-Cycle and the End-of Life-Cycle.

Comparing those 12 Design principles with the 8 EcoDesign strategies previously investigated it seems reasonably that the tools and applications to be used in the Product Life Cycle might be similar such as pollution prevention, cleaner production, recycling and waste management, environmental management system such as ISO14001 standard and EU Eco-Management and Audition Scheme that follow the quality management system philosophy of continuous improvement. There are no radical changes in the ways EcoDesign and Cradle-to-Cradle is implemented in the Product Life Cycle. It remains incrementally innovation based on the same set of beliefs, norms and standard practiced by the EcoDesign community.

3 Modularity as Open Innovation Generator

The material life cycle in the industrial ecosystem is at network of material cycles based on cooperation and linkages between different firms. These actors adapt to their surroundings with technologies, combustion and incineration techniques, production techniques, waste treatment techniques and other technical infrastructure for material cycles that are in a certain local industrial system. To function as an integrated sustainable supply chain working together up-streams in the product chain, but also down-stream requires the need to think holistic in the whole industrial ecosystem, and not just on those links which belong to its own sphere of legal responsibility.

Reuse, Remanufacturing, and recycling as end-of-life strategies, have addressed relatively little attention in the research community. It has earlier been presented the hierarchy of end-of-life strategies focuses on using simple product characteristics to make end-of-life strategy decisions (Figure 2). Strategies higher in the hierarchy minimize the environmental impact.

The most critical discipline is the design for disassembly. The aims is to design a product that can be readily dismantled at the end of it life and thus optimize the reuse, remanufacturing or recycling of materials, components and sub-assemblies. Driven by the economic imperative cost minimization, the simple and most cost effective assembly technique may result in a product that turns out to be exceeding difficult to disassemble. But product design designed with disassembly in mind very often proves to be more profitable, with economic benefits arising from: high quality image, modular design, upgrading of products, reduces components, reduced parts and materials inventories and fewer joints and connectors. Further, manufactures can benefit from generating a continuing revenue stream from the original materials by refurbishing their products.

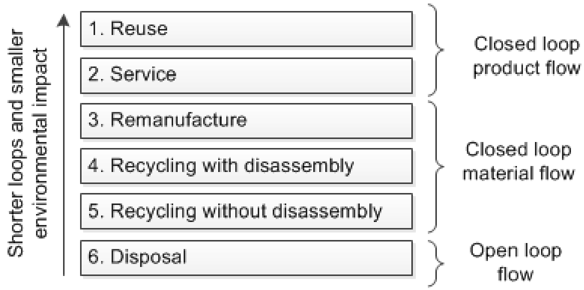

Fig. 2. Hierarchy of End-of-life strategies

The whole system is proposed to be understood as a modular system where each and every firm is a module whose structural elements are powerfully connected among themselves and relatively weekly connected to elements in other units. Each module consist of firm specific elements organized in its own way and with embedded knowledge infrastructure, integration of cleaner technologies, production systems, standards, planning procedures, worker skills and belief on sustainable initiatives. Modularity becomes the integration generator of modules by organizing the interdependencies among Product-Life-Cycle and End-of-Life initiatives so the socio-technical system function as an integrated whole. Transition to a sustainable system is founded on the configuration and alignment of heterogeneous elements and processes from each module into the renewal of an integrated networked supply chain. This broader innovation system perspective recognizes the need to radically new ways of organizing the socio-technical system instead of implementing isolated sustainable technologies into self-contain communities.

In emergent economies the collision between rapidly growing demand and a stable or diminishing stock of material supply will be the biggest challenge because industries depend on renewable resources The evolving focus on the industrial metabolism is a catalyst for a new round of creative destruction that offers unprecedented opportunities to foresight managers to rethink their prevailing views about strategy, technology, and markets.

4 Conclusion

The critical perspective on approached and means most popular in sustainable communities show these are isolated to the firm specific level and minimizing the volume, velocity and toxicity of the material flow system. The aim is to improve incrementally the performance of existing product and processes.

The industrial metabolism approach broader the problem of sustainable innovation by including the whole system perspective. This perspective calls for integration among embedded firm specific activities to form a renewal networked supply chain.

The paper proposes a modular approach as generator for development of a sustainable system taking account on both the social, economic and environmental elements. This multi-level perspective is evolving in the literature but much more work has to be done to improve its application into sustainable communities.

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