Proposal for an Architectural Solution for Economic and Environmental Global Eco-Cost Assessment: Model Combination Analysis

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Abstract This chapter highlights the complementarities of cost and environmental evaluation in a sustainable approach. Starting with the needs and limits for whole product lifecycle evaluation, this chapter begins with the modeling, data capture and performance indicator aspects. Next, the information issue, regarding the whole lifecycle of the product, is addressed. In order to go further than economical evaluation/assessment, the value concept (for a product or a service) is discussed. Value can combine functional requirements, cost objectives and environmental impact. Finally, knowledge issues are discussed, addressing the complexity of integrating multi-disciplinary expertise into the whole lifecycle of a product.

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1 Introduction

Sustainable concerns are increasing in the industrial sector. Different aspects, environmental, economic and social aspects, have to be considered (see Fig. 1). Most industries have turned "green due to regulatory constraints or marketing targets". As for quality management, industries have often adopted these changes as non-pro-active actors. There has been a shift from ISO 9,000 to 14,000. However, few industries have linked clear strategic policies to their priorities and their project's return on investment potential. Product definitions, manufacturing possibilities, logistics strategies and end of life alternatives offer many ways to work toward sustainability.

The social side of the sustainable approach is hard to deal with and is outside the scope of this chapter. However, this aspect should be taken into account very quickly in order to develop new service opportunities that meet consumer demand and optimize the product use ratio (real used time versus overall life time) and their environmental effect (Brissaud and Lelah 2010). There is a huge challenge to consider here, namely consumer and engineer tutoring. People have to learn to reduce consumption and pollution in order to adapt to the world's limited natural resources. Solutions have been found in green manufacturing and green alternatives, i.e. products that create less pollution at all stages of the product life cycle whilst ensuring minimal consumption of non-renewable resources. In addition, consumer tutoring has to focus on the way people use products and resources in their daily lives (e.g. water, light, etc.).

Cost and environmentally oriented industry decisions are therefore linked. Indeed, when engineers have to work in an environmentally-friendly way, their natural reflex is to aim to reduce the quantity of materials used and energy consumption. In this way, they not only reduce the product's impact on natural resources but they consequently also reduce material and energy costs within the global cost. Section 2 of this chapter will discuss the latter.

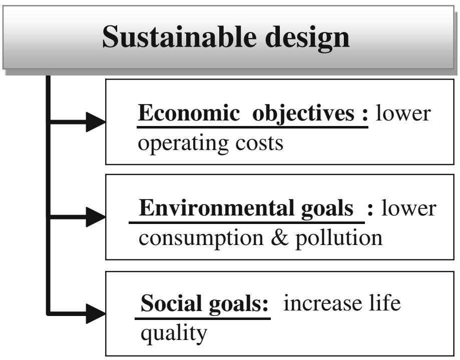

Fig. 1 Sustainable design goals

ISO 14062 defines eco design as the integration of environmental constrains in design and product development. Johansson (Johansson 2001) emphasizes that eco design encompass several concepts and definitions. He identifies the following terms: DfE stands for Design for Environment eco design, green design, life cycle design, eco-effective product design, to which can be added ecological design (Ventère 1995) or environmentally conscious design (Ritzén and Beskow 2001). Eco design can be seen as ambiguous, as it expresses, depending on the definition, a strategy, a process, an activity or even a product. Nevertheless Johansson notices that it is tacit or explicit in all definitions that the objective is to minimize the overall environmental impact of the product throughout its life cycle by adopting preventive actions during the design phase of the product.

In most cases, use and maintenance stage of the product involves the greatest impacts or costs. Then, overall cost of ownership is now the target of the designer and the marketing departments, and the same is true for environmental design and the use of Life Cycle Assessment (LCA, also called eco-balance or cradle-to-grave analysis) (EPA 2010). Figure 2 presents the different design interests for sustainable product/service development. A life cycle cost is one of the facet of sustainable design concerns and evaluations, in other worlds sustainable value. Section 2 will discuss the needs of an integrated Product Lifecycle Management system in order to evaluate efficiently all the stages impacted. Product information is unclear or unknown in the early phases when decisions are made and 80 % of the final costs have been determined (Blanchard 1978; Fabrycky and Blanchard 1991). The same problem arises for environmental consequences.

To define Product Lifecycle Management (PLM), product and process modeling are required. These models provide the basis for analysis and optimization of different solutions. The third section will present a value-based analysis approach such that not only cost, on the one hand, or environmental concerns on the other hand, can be taken into account, but value evaluation and value definition can also be proposed. This section will also introduce the links between value analysis and a PLM information system for sustainable analysis.

In order to ensure reliable evaluations, the data must reflect the reality. In addition, the aggregation rules must be adapted to the product portfolio, to organizational behavior and the evaluation criteria. In order to take advantage of previous or similar

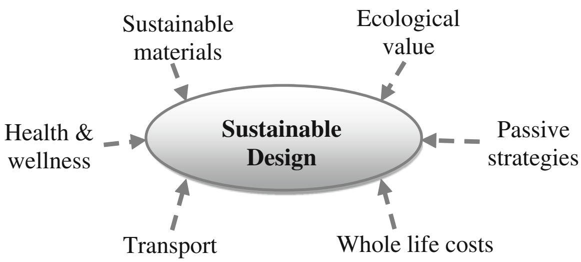

Fig. 2 Sustainable design interests

projects, it is necessary to look for the best practices for project guidelines and to locate the most important knowledge used. The last section will illustrate the use of roadmap methodologies and knowledge value evaluation to enhance and ensure the success of eco-design approaches in parallel to product cost assessment.

2 Cost and Environment Similarity and Complementarities

As for ISO 9000, ISO 14000 standards for environmental management systems are being developed to formalize the LCA method components (Viadu et al. 2006). Figure 3 presents a classic Product Lifecycle process. Each stage of the loop includes cost, and environmental impacts (consumption and pollutions). The aim of product life cycle costing and LCA is to evaluate performances on an overall cycle and sometimes on multi-cycles.

In the case of environmental impact, there are no data available to compare fixed impact due to design and global life cycle impact (such as for cost). But, excluding the usage phase, we assume that the ratio is quite similar. For a whole lifecycle evaluation, cost or environmental indicator definition and estimation are equally difficult. This section emphasizes the need for integrated information models and expert viewpoints to tackle the evaluation of the cost and environmental impacts over the whole life-cycle of a product or a service.

2.1 Full Lifecycle Model

Total lifecycle modeling is unachievable. Indeed, specific lifecycle phases have not yet a complete definition due to the possible detail of the basic activities (that

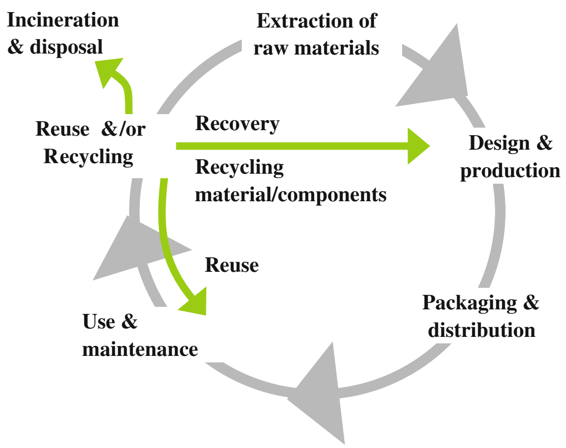

Fig. 3 Product lifecycle process

consume costs or affect the environment). Moreover, costs become shared results for a network of stakeholders (Mevellec and Perry 2006). They shift from a productive industry (mainly direct costs linked with manufacturing costs) to a cognitive and worldwide networked industry (with major allocations related to indirect costs linked with research and development stages) (Bouin and Simon 2000). As a result, the product lifecycle phases are already partially formalized. These phases can be more easily populated and monitored and indeed, the process definitions (required by ISO 9000 standards) provide a good basis for extracting and aggregating manufacturing costs. However, in a world where innovation and R&D projects maintain competitivity, the associated overheads costs are not easy to assess with real data. At the end of the product lifecycle, there is no rule that guides designers concerning the impact of whole costs on the final estimate. Depending on the alternatives, some financial advantages can be introduced into the loop. For example, reuse as second life sub-systems or material recycling can generate positive financial flow and reduce the global bill.

The same problems arise from environmental indicators. They have to take consumption of resources into account (mainly raw materials and energy), different types of pollution and emissions (solid, liquid, gaseous) and their impacts (human, eco-system, ground, water, atmosphere, etc.). As for cost analysis, some life phases or resource consumption can be monitored easily, such as power supply factories, distribution in a known supply chain, etc. However, in a continuously moving network of enterprise, many measurements depend on the network's dependencies. Consequently, evaluations may be inaccurate during the product development stage. The criteria that are in fact used to choose suppliers are far from the scope of environmental issues. Moreover, the end of life may have a great impact. Depending on the existing recycling paths, or developed technology, this impact could be positive and enhance the global environmental dependence. Burning or landfill solutions will no longer have a future. Industry and designers have to consider this impact in their future designs and developments. Automotive regulations for 2015 will limit the percentage of CO_2 emission but also impose a high ratio of recycling for end of life vehicles.

The use phase of a product can be hard to evaluate. In a Business-to-Business relationship, this phase is quite well defined and could lead to good evaluations, whereas Business-to-Consumer products could lead to unusual uses which in turn lead to unexpected costs or environmental consequences. In the case of a LCA, the use and maintenance phase may be the most noxious and designers and industry can have little impact upon it. This is where the designer's options start to be limited. Efficient information and customer tutoring can lead to achieving real sustainable products.

Even if it seems impossible to completely define the whole lifecycle, similarities and complementarities arise from the two modeling points of view: cost and environment. In each case, product evolutions have to be modeled and evaluated. Energy and material consumption are required data for both. Product transformation models are also sources of common rating. Thus, process and product models are used to perform cost analysis and product LCA through different stages of manufacturing, use, and end-of-life options. The system can be analyzed using process flow diagrams which show that the inventory of environmental impacts and resources used is comparable. This provides joint cost and environmental analysis (Hendrickson et al. 1998; Satish 1999).

2.2 Full Lifecycle Information

Most of the time, the expected lifecycle information is defined only partially or not at all in the early phases when decisions are made (Guinee 2002). As a result, it is hard to develop cost or environmental design strategies which could guide designers efficiently, due to these unreliable values. Specific risk analysis evaluation should be done at the key stage of the product-process development. A contingency analysis would allow the variability of the results to be measured and highlight the main incident factors (Wimmer et al. 2004). These methods are still under validation from an environmental point of view.

It seems possible to have detailed information made available for some stages like manufacturing, packaging and transport or recycling processes. However, even in these cases, the real data are not so easy to capture (Perry et al. 2007). Nowadays, the supply chain is worldwide, and the reality of modeled processes and data collection are hard to guarantee (Degos 1998). This is the case for cost evaluation and the environmental aspect despite the standard framework imposed on the suppliers.

Consequently, calculations must be made using unknown data and in most cases have to be interpreted as relative values. Thus ranking a new product or product process alternative might be risky.

2.3 Multi-Data Aggregation

Another common issue remains regarding the need to calculate with multiple kinds of data. In the case of LCA, the environmental impacts included are: global warming, acidification, energy use, non-renewable consumption, water eutrophication, gas and toxic emissions to the environment, etc. This combination of multiple and non-homogeneous data highlights the issue of indicator design and equivalence definition. Some research proposals have started working on unified metric units. For instance, decibels have been proposed as a possibility (Coatanea et al. 2007). This solution has no unity dependence and indicates the contribution or losses of the value (the decibel is calculated as a ratio compared to a nominal value) (Seager and Theis 2004). The energy equivalent calculation is another possibility. This thermodynamic concept measures material and energy resource consumption for each impact (Szargut et al. 1988).

In the same way as having a unique cost indicator, Perrin promoted the single value added unit methodology (Perrin 1963 and 1996). This proposal tries to find an independent cost unit that could facilitate true representativeness and hence the final aggregation. In fact, Perrin realized that the analytical accounting system is not adapted to industrial reality. Using the same philosophy of cost independence, target costing or activity-based costing approaches were developed and adapted for use and integration in design methodologies (Gosselin and Mevellec 2003; Innes et al. 2000).

Based on these studies, the concept of value promoted by Porter emerges as a global and transitional concept applied to both costs and environmental analysis (Norman and Ramirez 1993; Porter 1998). Indeed, traditionally, value includes different factors such as cost, quality, delay, and enables value chain evaluation and optimization to be carried out (Kaplinsky 2004; Mauchand et al. 2010). This notion of value is easily extended to environmental aspects.

3 Lifecycle Engineering and Product Lifecycle Management Based on Value Evaluation

As mentioned in the previous section, whole lifecycle evaluation means formalization and information at all stages of the product development. Nevertheless, the product itself cannot be the only focus. The processes that support product development, manufacturing, using step and end of life dismantling also have to be taken into account. As a result, the information system that supports such approaches must consider both product/process as well as different stakeholder viewpoints (Mevellec and Lebas 1998).

3.1 The Value Framework for Cost and Environment Combined Analysis

To ensure an efficient twin-eco evaluation (economic and ecological), it is necessary to quantify the alternatives for product and processes. This quantification will be functional, economical and environmental. In order to take stakeholders' viewpoints into account, each aspect has to be weighted. The final choice will be made according to the strategy or the enterprise objectives.

Value is a concept that enables different factors to be analyzed independently or in combination. According to the European standard (EN-12973), the value analysis is effective in improving the performance and taking into account other factors than cost. The evaluation of the performance of a company is not limited only to its financial performance. The value is the consumer's overall assessment of the utility of a product based on perceptions of what is received and what is given (Zeithaml 1988). Butz and Goodstein (Butz and Goodstein 1997) define customer value as the emotional bond established between a customer and a producer after the former has used one (or more) product (s) or services produced by the latter and found it of added value.

According to Porter (Porter 1998) a value chain is formed of a set of value generating activities and is used to diagnose a competitive advantage as well as to find ways to strengthen it. The value chain according to the AFNOR FD X50-158 is defined as all activities of the organization divided into cost elements and contributing to the final value of the product or service. Extending this concept, Elhamdi defines a value network as a group of partners collaborating in order to create value (Elhamdi 2005). He argues that value is linked to a beneficiary party. Hence, the generated value of the network does not concern only the company itself, but all other parties who are beneficiaries thus who derive interest or satisfaction. Performance and value indicators, presented in Fig. 4, come from a reflection on the benefits of product manufacture for each benefiting entity (Mauchand et al. 2010).

Mauchand proposes a product-process data model focusing on value chain modeling and evaluation (Mauchand et al. 2010) (Fig. 5). This model needs to integrate lifecycle concepts in order to enrich the value concepts with environmental concerns. For example, the process can be extended to product stages, and will represent all the steps illustrated in Fig. 3. Labrousse links the Product Process Resource model to the Functional Behavior Structure view (Labrousse et al. 2004). This solution gives the opportunity of managing both value and value chain evaluation (using the model in Fig. 5) and the dynamic aspect of the life cycle evaluation.

For any product (set of N functions), there are different technical solutions to meet the needs. In addition, for each solution, the process alternatives (composed of a set of activities) can lead to the product development and use. For each path, a value chain can be defined, as illustrated in Fig. 6.

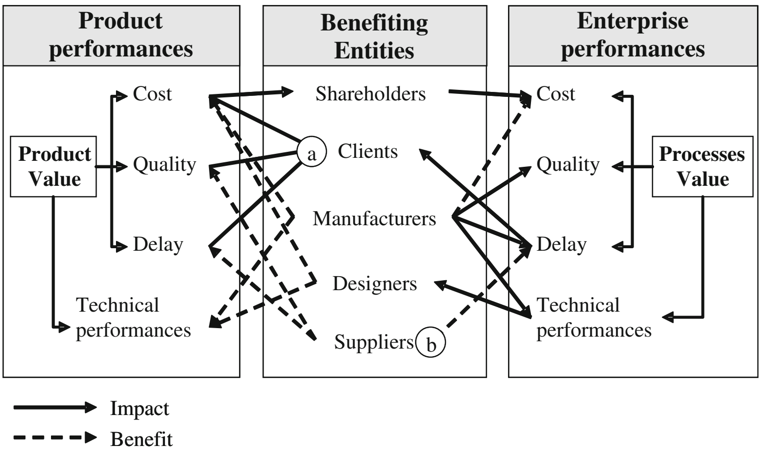

Fig. 4 Performances that affect value and their interactions with benefiting entities

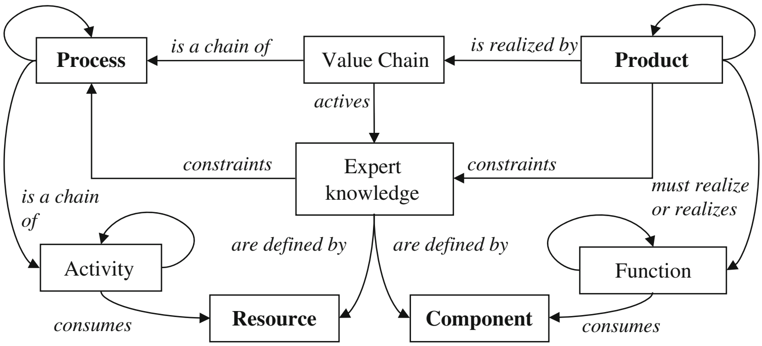

Fig. 5 Structure of the concepts for industrial system modeling (Mauchand et al. 2010)

Using this method, Mauchand proposes a Value Chain Simulator (VCS) that can compare solutions (Mauchand et al. 2010). Depending on the weights applied related to the benefiting entity interest, the solution will balance high technical performances oriented possibilities, low cost (or adapted market) solutions and environmentally friendly proposals. The structure and basic elements of the VCS are illustrated in Fig. 7.

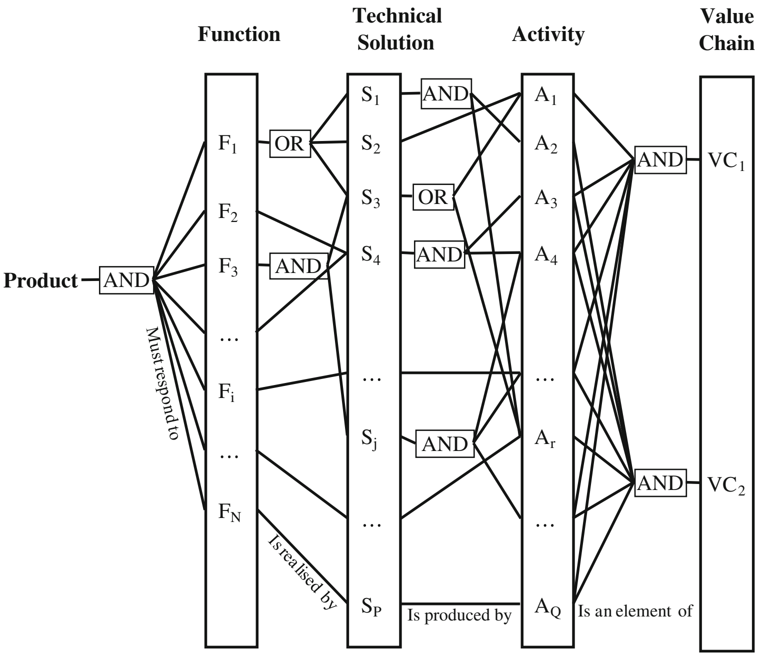

Fig. 6 Choice process of value chain alternatives

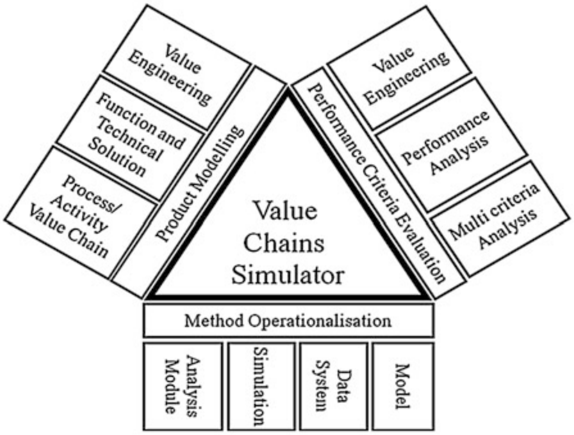

Fig. 7 Value chains simulator architecture (Mauchand et al. 2010)

Despite all the excellent qualities of this proposal, there is still something missing in terms of lifecycle simulation with such tools. Indeed, the model and data system required for the simulation are scarcely complete. This tool has been dedicated mainly to the manufacturing phase and must be adapted to the other product lifecycle stages.

3.2 PLM System Definition

In order to ensure a full product lifecycle evaluation, the life model and life use phases have to be represented and completed with relevant data.

PLM can ensure the information flow by linking the product definition files through the whole lifecycle. An acceptable definition of PLM is: "A strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination and use of product definition information across the extended enterprise from concept to end of life—integrating people, processes, business systems, and information" (Amann 2002). PLM is generally associated to a set of applications linked to the product development. In this way, PLM systems include or tend to include PDM, MPM, ERP, CMMS and LCA systems. Those information systems store information for each stage of the product lifecycle except the use and maintenance phase. Concepts such as closed-loop PLM tried to overload this issue, extracting information from the product during the use step using wireless technologies. The concept of closed-loop PLM can be defined as follows: a strategic business approach for the effective management of product lifecycle activities by using product data/information/knowledge which can compensate PLM to realize product lifecycle optimization dynamically in closed loops with the support of product embedded information devices (PEID), product data and knowledge management (PDKM) system (Jun et al. 2007).

PLM systems rely on a data model composed of business objects that intervene in business processes and in product portfolios. Several modeling methods and languages have been developed to model these objects (Bernard and Perry 2003). Some of the many languages used to represent these objects and related activities are SADT or IDEF3, Business Process Modeling Notation (BPMN) (White 2004) or Functional Behavior Structure (FBS) coupled with Product Process Resources and External effects (PPRE) (Bernard et al. 2005). The establishment of patterns, based on this language, describes an approach to represent the processes. CIMOSA (Kosanke and Zelm 1999), ARIS (Scheer 1998), GRAI (Doumeingts et al. 2006) and PERA (Williams 1994) are modeling languages and modeling methodologies that must be adapted for PLM implementation.

Le Duigou proposed a PLM structure adapted to SME's. Supported by the French Technical Institute of Mechanical Industries (CETIM), the aim of this proposal was to provide a PLM solution for SME's. With this PLM information system, they can get into an extended enterprise structure with measured investments and time (Le Duigou et al. 2009). Based on a Product—Activity—Resource—Organization meta-data structure (see Figs. 8 and 9), this proposal has to be aligned with the previous value-based proposal, in order to be used to assess the product lifecycle model.

This PLM proposal is based on SME needs and requirements analysis (Le Duigou et al. 2012). Consequently, it is not completely adapted to the cost and environmental evaluation. Indeed, the different indicator measures can be implemented at all the levels: product, activity, resources and organization. It appears that if these data are available, the activity and the resource views could quickly give pertinent ratings. In the case of the product, the different lifecycle steps are represented by the different activities linked to the product (design, manufacture, use, disassembly, etc.). In the case of the use and maintenance phase, alternative uses (i.e. non-nominal) are represented by alternative activities in use and maintenance process. This makes it possible to evaluate the product and the impact of customers (depending on their behaviors). This example gives an idea of what a PLM system with evaluation facilities could be.

4 Knowledge Management for Virtual Engineering-Based Evaluation Discussions

In order to ensure high quality and efficient evaluations, the model should not only be adapted to the whole lifecycle, but the calculated rank should also be proposed with contextual information and data that reflect reality. Calculation and aggregation rules, data source reliability and model representations must be available for

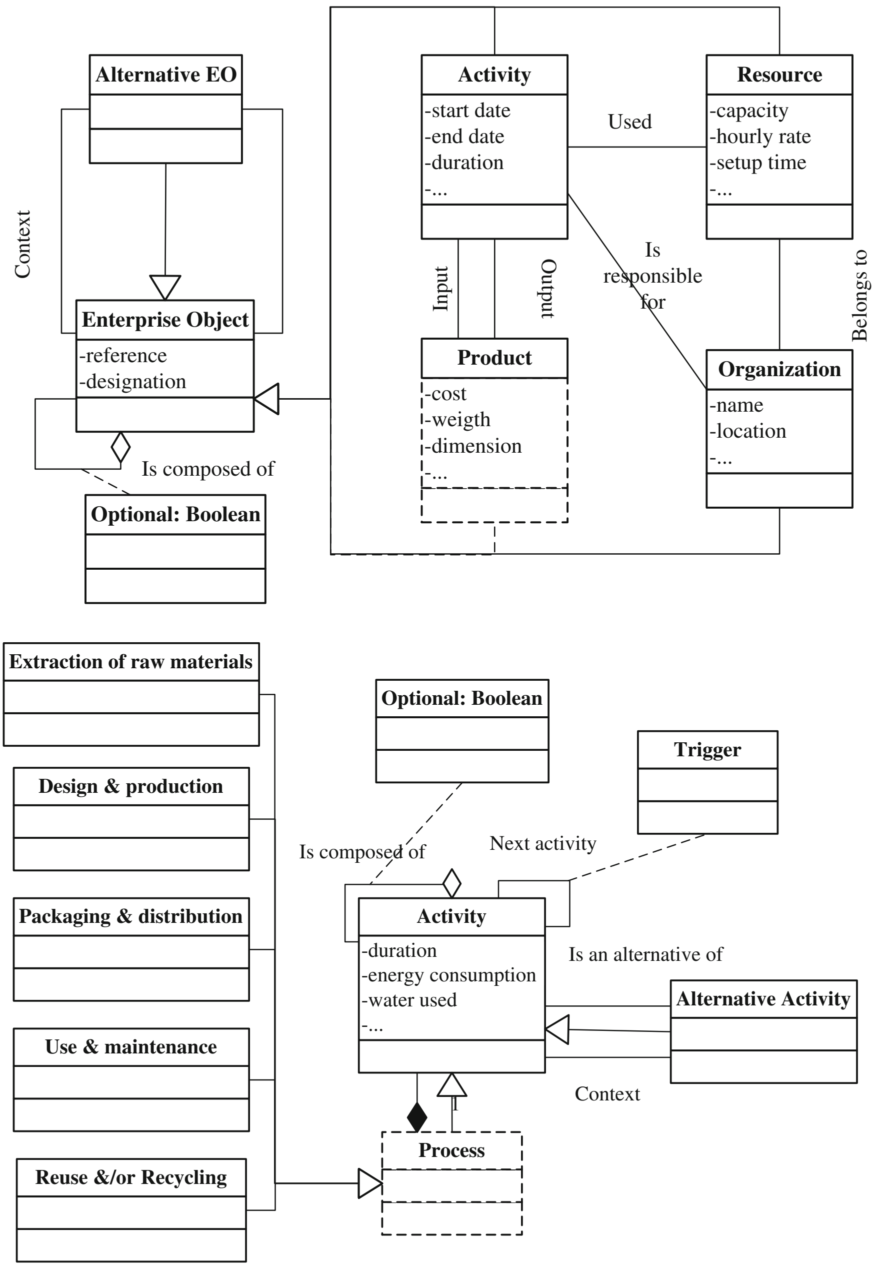

Fig. 8 Product activity resource organization meta-model (Le Duigou et al. 2011)

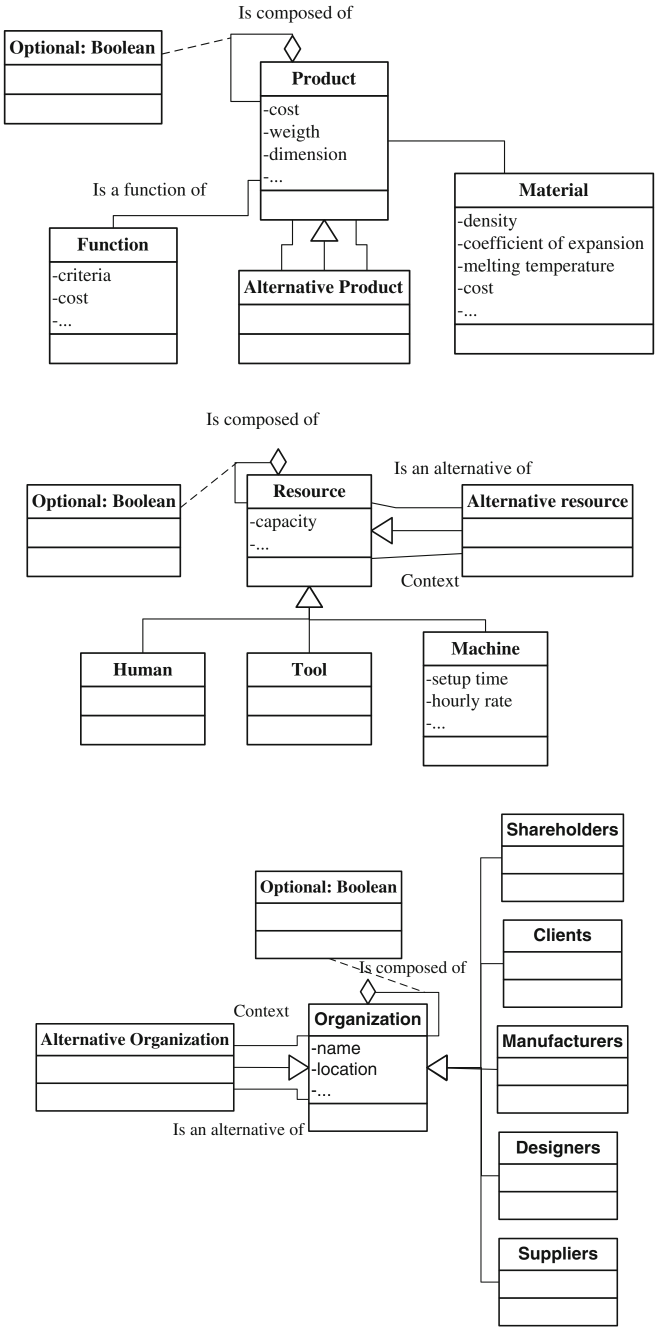

Fig. 9 Product, activity, resource and organization models (Le Duigou et al. 2011)

the contextualization of results. Consequently, knowledge from different experts must be integrated into knowledge-based systems. These systems must be interoperable with all the specific tools from the modeling phase and data capture to evaluation and results comparison or optimization. Virtual engineering environments allow the integration of all the lifecycle models (Bernard 2005). Engineers have new media to interact with the different numerical representation and simulation models. They use them to define and industrialize complex systems that must integrate more and more perspectives in a short time. The challenge is in improving product development environments and designing virtual engineering platform software that takes all the product and system lifecycle phases into account, and integrate knowledge (Bernard et al. 2007).

Consequently, knowledge tracking, identification and formalization, from different forms of expertise, at different levels of detail, must be carried out and integrated into knowledge-based engineering platforms (Ammar-Khodja et al. 2008). Specific methods ensure the coherence and consistency of these knowledge-based system developments. In order to ensure multiple expertise coherence and interoperability (from the knowledge and software point of view) various integration models exist, and ontology-based approaches seem very promising for the future 2.0 technologies (Bigand et al. 2007; Bachimond et al. 2002). For instance, a specific ontology definition of concepts like cost has already been proposed (H'Mida 2002) and can be combined with environmental or sustainability ontology (Missikoff et al. 2002).

Exchanged documents and previous projects are the information repository areas that can be exploited to enrich the expected knowledge (of costs and environmental evaluation) (DuPreez et al. 2005). From these documents, key knowledge can be identified. Xu proposes a knowledge value rating system to optimize the best evaluation models, representative methodologies or efficient software that can be used to quickly and precisely match the product or system cross evaluations (Bernard and Xu 2009; Xu and Bernard 2009). With this proposal it becomes possible to select the relevant evaluation techniques, according to the level of product development, information maturity, perspectives and target constraints. Such an operational system is not yet in use. The basic components of knowledge evaluation have been proposed and offer promising possibilities to browse and select the most efficient and pertinent elements to be integrated into the global knowledge database. The wish to integrate the knowledge of several experts into all phases of the product life cycle leads to a huge system that is unmanageable and unusable. Information reduction coupled with intelligent information technologies (i.e. 2.0) can reduce these risks. This is why many actors of the worldwide community have focused on methods and tools for effective knowledge life-cycle management (Bernard and Tichkiewitch 2008).

5 Conclusion

This chapter highlights the complementarities of cost and environmental estimates. The same needs and limitations for whole lifecycle evaluation appear for cost or environmental applications. Some representations of the lifecycle phase are missing from the modeling level due to absent data or unknown solutions for these phases. The data capture level for simulation lacks accuracy or sensitivity analysis for evaluating the quality of the results in terms of confidence or main factor impact. The performance indicators, the cost or environmental impact, can be analyzed separately or combined under a common such as the value concept. PLM possibilities, dedicated to data management and product information management relating to lifecycle, can therefore be adapted to support the different eco-calculations (from an economic and/or ecological point of view). In addition, to ensure a good level of result contextualization and best practice integration, expert knowledge must be included in a knowledge database. These knowledge databases are structured to support the definition and the development of agile virtual engineering platforms. Modeling tools may differ from one phase to another and the kind and quality of information will be at different levels. In order to maintain coherence and ensure agility with future software integration in the engineering method, ontology-based systems can offer solutions for service-oriented architecture for platform development.

This type of global approach cannot be addressed in a single project or test case, but results from development strategies for the different components identified in a system and their integration into a coherent global proposal.

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