The role of lcc and lca environmental sciences essay

Chapter 2

Introduction

Nowadays, the worldwide economic downturn force the manufacturer and they suppliers to cut cost and enhance the performances of their process in order to survive in the market. Furthermore, environmental protection is becoming more and more important and green manufacturing has become an expected practice that should be integrated in the development of industry [DEN 13]. Motivated by the cost and environmental concerns, Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) were developed to exploit a simple and intuitive concept: every stage in the life cycle of a product or process has both costs and environmental impacts [FIK 96]. In this scenario it is mandatory for the company to think of the whole lifecycle of product and seek to identify new competitive leverages. Based on those recognitions, environmental impact must be weighted, balanced and optimized against other concerns, such as Life Cycle Costs (LCC), availability and time to market etc. These multiple, often conflicting objectives pose a challenging and complex optimization problem [YU 01]. As the proposed model is aimed at optimization of Life Cycle Costs (LCC), Life Cycle Assessment (LCA) and performance as Availability (A), Reliability (R), it is necessary examine the approaches for Product Life Cycle Optimization (PLCO). This chapter first reviews the definition and the role of the LCC and LCA. Then, include related previous studies on integration and optimization methodology of LCC and LCA.

The role of LCC and LCA

LCA and LCC both originates from the energy crisis in the mid 1970ies. LCC was developed by economists (economic focus) and LCA by engineers (focus on mass and energy balance). Barringer 1996 defined that Life cycle costs LCC are " cradle to grave" costs summarized as an economics model of evaluating alternatives for equipment and projects. In other words they are summations of cost estimates from inception to disposal for both equipment and projects as determined by an analytical study and estimate of total costs experienced during their life [BAR 96]. In the other hand, Life cycle assessment (LCA) is a methodological framework for estimating and assessing the environmental impacts attributable to the life cycle of a product, such as climate change, stratospheric ozone depletion, tropospheric ozone (smog) creation, eutrophication, acidification, toxicological stress on human health and ecosystems, the depletion of resources, water use, land use, and noise—and others [REB 04]. LCC developed quickly as there was already a methodological framework: economics. The main problems were to find the items to include and to estimate their values. LCA developed more slowly. Initially, the focus was energy balances. Then, mass balances were added, including material and waste streams. Later, environmental assessments were made for the mass and energy balances, and the framework developed gradually. So far, there has been a significant development of LCA, both in terms of methodology and applications. Nowadays, both methodologies are widely used in the decision making of product design as measure and assessment of costs and environmental performances. However, LCA typically does not address the economic aspects of a product. Effectively, LCC and LCC are each designed to provide answers to very different questions. Life Cycle Assessment evaluates the relative environmental performance of alternative product systems for meeting the same end-use function, from a broad, societal perspective. Life Cycle Cost evaluates the relative cost-effectiveness of alternative investments and business decisions, from the perspective of an economic decision maker such as a manufacturing firm or a consumer. Despite the fundamental role of LCC and LCA in the decision making process, the product design should not only considers the economic and environmental aspects but should ensure the design's compatibility with related physical and functional requirements. Therefore, it should take into account also the life of product as measured by its performance such as availability, reliability, maintainability, capability, system effectiveness etc [FAB 91](Figure 2. 1). Figure 2. The use of LCC/LCA and performance in the decision making of product design.

Similarities and differences of LCC and LCA

According to Norris (2001) the differences in the purpose of LCC and LCA lead to differences in their scope and method. The observation of some similarities between LCA and LCC could be misleading, making their integration seem simple or even intrinsic to their very nature. Indeed, the likeness of their name state a " life cycle thinking" approach. Moreover, their system based approach manifested in LCA by the distribution of physical flows (resources, polluting substances, waste) in the context of the system of elementary activities, and in LCC by the breakdown of economic flows in a Cost Breakdown Structure (CBS), in some cases structured according to the product's physical life cycle. Finally, the opportuneness of operating both analysis, environmental and economic, in the preliminary phases of product development, in that both the environmental impacts and costs of the life cycle are strongly conditioned by the first design choices. The methodological similarities are summarized in Table 2. 1.

Tool/Method

LCC

LCA

Life Cycle ApproachAre " cradle to grave" costs summarized as an economics model of evaluating alternatives for equipment and projects [BAR 96]. Is a method to identify and quantify the environmental performance of a process or a product from " cradle to grave" [AZA 99]System based approachThe distribution of the physical flow allow to classify the basic events in a product's life-cycle. In CBS all the costs and revenues of a product over its entire life are quantified. Influence by early design decisionThe costs incurredduring the production, use, and disposal are mostly committed by early design decisions [SEO 02]. The environmental impacts incurred during a product's life cycle are mostlycommitted by early design decisions [PAR 01]. Table 2. Errore. Nel documento non esiste testo dello stile specificato. Similarities between LCC and LCADespite those similarity, often the " life cycles" being addressed by each method are different. LCC analyzes the cost-effectiveness of an investment over its economic lifetime, which is related to the usage phase in LCA. The time horizon of an LCC analysis is often even shorter than the usage phase of the investment, and is set by the accounting conventions of the decision maker. The aims of analysis are completely different. The aim of LCA is to evaluate the environmental performance of products and alternative choices guaranteeing the same functions, from the perspective of benefit for the whole of society. The aim of LCC is to evaluate the economic effectiveness of investments and alternative choices from the perspective of the actor making the decisions. Another difference is the extension and typology of life cycle model. LCA examines the entire system of processes and activities connected with the product's physical life cycle. LCC considers the set of activities resulting in costs or revenues for the decision maker. This results in a difference not only in the extension of the life cycle (which in the case of LCA can also include activities and physical flows not associated with direct economic consequences for the decision maker) but also in the typology of the model describing the life cycle, because not all the monetary flows can be directly attributed to the physical flows considered in LCA. At the end there is an unequal influence of the time variable. The life cycle model for LCA does not usually take account of the temporal distribution of resources, wastes, and emissions. Instead, in the analyses for LCCA the time variable assumes a determining role in the evaluation of monetary flows; LCCA requires a clear definition of the duration of the time span, beyond which these flows are ignored. The methodological differences pointed out by Norris (2001) are summarized in Table 2. 2 [NOR 01b].

Tool/Method

LCC

LCA

PurposeDetermine cost-effectiveness of alternative investments and business decisions, from the perspective of an economic decision maker such as a manufacturing firm or a consumer. Compare relative environmental performance of alternative product systems for meeting the same end-use function, from a broad, societal perspective. Activities which are considered part of " Life Cycle" Activities directly causing costs or benefits to the decision maker during the economic life of the investment as a result of the investment. All processes causally connected to the physical life cycle of the product; including the entire pre-usage supply chain; use and the processes supplying use; end-of-life and the processes supplying end-of-life steps. Flow consideredDirect costs and benefits to decision makerPollutants, resources, and inter-process flows of materials and energy. Units for tracking flowMonetary units (e. g., Yen, dollars, euro etc.)Primary mass and energy; occasionally volume and other physical unitsTime treatment and scopeTiming is critical. Present valuing (discounting) of costs and benefits. Specific time horizon scope is adopted, and any costs or benefits occurring outside that scope are ignored. The timing of processes and their release or consumption flows is traditionally ignored; impact assessment may address a fixed time windows of impacts but future impacts are generally not discounted. Table 2. 2 Differences between LCC and LCA [NOR 01b]

Consequences of the gap between LCC and LCA

The mentioned before separation of LCA and LCC triggers three important consequences [NOR 01a]: Limited influence and relevance of LCA for decision making. A company cannot afford to make product design decisions on strictly an LCA basis, without regard to economics, product performance, etc. Even in an idealized scenario where life cycle environmental performance is the only objective in a product design or selection decision, economics needs to be part of the analysis because there are only limited resources with which to pursue this sole objective. That is, even if we only care about environmental performance, we must consider the variable economics of alternatives, in order to identify the decisions through which our limited resources can achieve the best environmental performance. Inability to capture the important relationships and trade-offs between the economic and life cycle environmental performance of alternative product design decision scenarios. This is the missed opportunity which remains even after a separate cost analysis is performed in parallel with an LCA. It is the result of not integrating economic analysis with LCA. Models which treat both economics and life cycle environmental results simultaneously in an integrated fashion can enable decision makers to examine trade-offs and relationships. Potential to miss economically important or in some cases even economically pivotal environment-related consequences to the company of alternative decisions. Economic analysis with an entire life cycle perspective will broaden the discovery of " hidden" cost and revenue impacts that are otherwise neglected in conventional economic analyses. This is especially true when the class of economic considerations includes cost and revenue risks, such as those related to accidents, liabilities, consumer perceptions, etc. Analyzing the consequences it is possible to assert that product designers cannot make final decision only depending on environmental assessment results or on economic aspects. In fact, it is difficult for companies understanding of what the result of LCA means to their economy. Thus, it is necessary to integrate and optimize together LCA and LCC (Figure 2. 2). Figure2. Consequences of the gap between LCC and LCA

Linking LCC and LCA

The gap between LCC and LCA leads a need of a combined use of the two methodologies. Several study have been done in this area, but few of them were in the field of product design and manufacturing. Analyzing the literature it possible identify that the effort were mainly made in two branches: Integrating modelOptimization model

Integrating LCC and LCA

Many attempts have been made at integrating the assessment of environmental and economic performance of alternative products or product design decision. Currently there are two main methods applied in integrating LCA and LCC [DEN 13]. One method is to integrate economic considerations into the process of LCA. According to Norris (2001) standard methods of LCA can and have been tightly, logically, and practically integrated with standard methods for cost accounting, life cycle cost analysis, and scenario-based economic risk modeling. He outlined two approaches PTLaser and TCAce [NOR 01a]. Reich (2005 proposed a terminology for economic assessment and a methodology combining financial LCC, life cycle costing, (which is used in parallel with an LCA) and an environmental LCC (functioning as a consecutive, weighting tool) and LCA [REI 05]. Interesting is the contribute given by Bovea et al (2004 which pointed out a model based on the combination of three methodologies: Life Cycle Assessment (LCA) methodology to evaluate the environmental requirements, Life Cycle Cost (LCC) to examine the internal and external costs of the product, and

Contingent Valuation (CV) to quantify the customer's value in terms of his/her willingness-to-pay (WTP) for a product that incorporates certain environmental improvements [BOV 04]. The other method calculates environmental cost by integrating LCA and LCC. Steen (2004 in his work uses LCA for identifying and estimating environmentally related cost items in an LCC [STE 04]. Gòralczyk and Kulczycka proposed a tool to evaluate the economic and ecological feasibility of new and existing projects using a combination of environmental goals expressed in life cycle assessment (LCA) results with economic goals expressed within life cycle costing (LCC) [GOR 06]. Senthil et al. (2003 developed a life cycle environmental cost analysis (LCECA) to estimate and correlate the effects of these costs in all the life cycle stages of the product. Deng (2013 proposed a framework of integration of LCA and LCC has been introduced, which is contained by four components: the definition of unity time and physical boundaries, integration of inventory analysis, integration of impact assessment, environmental and economic interpretation. The model suggested by Simoes et al. applies the LCA methodology to the product system and, concomitantly, incorporates the results into the LCC study, namely the life cycle inventory (LCI) and life cycle impact assessment (LCIA). Finally, Zhang 1999 introduced a Green QFD-II integrating LCA and LCC into QFD matrices and deploying customer, environmental and costing requirements throughout the entire product development process. A summary of key points of previous related studies on integrating LCC and LCA provided in Table 2. 2 below.

Literature

Approach

Method

Application field

Norris 2001PTLaser and TCAceIntegrate economic considerations into the process of LCAProcess and product design decision making; Reich 2005Integrating financial LCC, life cycle costing and environmental LCC and LCA. Integrate economic considerations into the process of LCAWaste managementBovea et al. 2004Combining Life Cycle Cost , Life Cycle Assessment and Contingent ValuationIntegrate economic considerations into the process of LCAEnvironmental product designSteen 2004LCA as input of LCCCalculate environmental cost by integrating LCA and LCCDecision makingGòralczyk and Kulczycka 2006Tool to evaluate the economic and ecological feasibility of a project using a combination of environmental goals. Calculate environmental cost by integrating LCA and LCCMining industrySenthil et al. 2003Life cycle environment cost estimation modelCalculate environmental cost by integrating LCA and LCCEnvironmental product designDeng 2013Framework of integrationCalculate environmental cost by integrating LCA and LCCProduct designZhang 1999GQFD-II integrating LCC and LCACalculate environmental cost by integrating LCA and LCCEnvironmental product designSimoes et al 2013The LCA/LCC integrated modelconsists in using, in parallel, theLCA and the LCC methodologiesCalculate environmental cost by integrating LCA and LCCRaw material productionTable 2. 2 Summary of relevant LCC and LCA integration model

LCC and LCA optimization

In the process of product design, the integrated evaluation results often indicates that the relationship among economic and environmental aspects are not in balance. It means that optimization is as important as integration [DEN 13]. Also Azapagic 1999 pointed out that the environmental and economic performance of the system can be optimized together to find the best compromise solution for the improvements in the system. Thus, incorporation of life cycle thinking into the design and optimization procedures establishes a link between the environmental impacts, operation and economics of the system [AZA 99]. Effectively, optimization helps to find the answer that yields the most desirable result. Optimization method is a way of finding the optimal solution which meet or exceed the targets of the optimization model. It has one objective or multiple objectives. Because of the nature of the decision-making process in the LCC and LCA context, the optimization problem will inevitably be a multi-objective. Many studies have been carried out on multi-objective optimization and a series of relevant optimization models can be discovered from literatures. Even though there are a large number of papers on optimization, most of them not referred to the product design. Indeed, there are several studies on green building design and many application in the maintenance of infrastructure. This section intends to provide a comprehensive and in-depth review of the relevant multi-objective optimization models in all field developed in past literatures involving LCC and LCA. The emphasis is placed on the design objectives, the methods for evaluating the design objectives, and the algorithms based on which the optimization process is conducted. In term of number of design objectives previous relevant optimization model for product design can be roughly divided into two groups, single-objective and multi-objective optimization model. Most early optimization models were developed considering only one design objective. Moreover, due to the lack of suitable solution techniques, lots of multi-objective problems were artificially converted into a single-objective problem and solved [DEB 01]. One of the first contribute of using multi-objective optimization was given from Hyun et al. (1998), their work involved a new genetic algorithm used to solve multiple objective sequencing problems in mixed model assembly lines [HYU 98]. Another early adopter of multi-objective optimization was Azapagic (1999) which used a three-objective system optimization in LCA as a tool for identifying and evaluating the best possible options for environmental management of the product system [AZA 99]. Wright et al. (2002) developed a multi-objective optimization model to optimize HVAC system design and control parameters with two design objectives: to minimize the operating cost for the design days and to minimize thermal discomfort [WRI 02]. Brown and Salcedo (2003) proposed the application of multiple-objective genetic optimization to a naval ship design problem, the critical objective attributes considered are mission effectiveness and cost [BRO 03]. In the field of civil structure Liu et al. (2004) pointed out a multi-objective optimization approach for solving life-cycle cost oriented seismic design of steel moment frame structures. Initial cost and lifetime seismic damage cost are considered as separate objective functions subject to simultaneous minimization [LIU 04]. Wang et al. (2005, 2006) in their works proposed two model: the first for the optimization of green building design; the second for the floor shape optimization. Both optimizing Life Cycle Costs (LCC) and Life Cycle Environmental Impacts (LCEI) , using Genetic Algorithm (GA) [WAN 05]

[WAN 06]. In the study of Fragiadakis et al. (2006), Material weight and LCC are the two objectives optimized by an Evolution Strategies Algorithm [FRA 06]. Verbeeck and Hens (2007) performed a life cycle optimization for extremely low energy dwellings aiming at reducing financial costs and ecological impact over the life cycle. The life cycle ecological impact was evaluated through life cycle assessment (LCA) [VER 07]. Frangopol and Liu (2007, 2011) focused their effort reviewing the recent development of lifecycle maintenance and management planning for deteriorating civil infrastructure with emphasis on bridges using optimization techniques and considering simultaneously multiple and often competing criteria in terms of condition, safety and life-cycle cost [FRA 07][FRA 11]. Also Okasha (2009) in collaboration with Frangopol used genetic algorithms in order to optimize construct system structure problems considering system reliability, redundancy and LCC [OKA 09]. In the mechanical product design Deng et al. (2008, 2013) considered the integrated environmental (LCA) and economic benefit (LCC) as objective of the multi-disciplinary optimization [DEN 08] [DEN 13]. Tuhus-Dubrow and Krarti (2010) developed a simulation-optimization tool based on DOE and GA to minimize energy consumption and LCC for residential buildings [TUH 10]. Cerri 2011 in his work of thesis applied a Not-dominated Sorting Genetic Algorithm for minimizing LCA and LCC in the product design process [CER 11]. Another thesis written by Ganjidoost (2011) point out a methodology using a Multi-Objective Linear Programming in order to minimize LCC and LCA in the building design [GAN 11]. Allacker (2012) optimizes environmental and economic aspects of the floor on grade in residential buildings searching the Pareto optima out of large number of option [ALL 12]. Similar works were carried out by Flager et al. (2012) and Fesanghary et al. (2012) in building sector, indeed both proposed a multi-objective optimization (using different methodologies) due to minimize LCC and environmental aspects (respectively carbon footprint and CO2 emissions) [FLA 12] [FES 12]. Another relevant work of thesis in the same field is realized by Hao (2012) which presents a three design objectives model evaluating LCC, energy consumption and comfort level of indoor environmental quality. The developed model was optimize by Non-dominate sorting Genetic Algorithm [HAO 12]. Also Hamelin et al. (2012) present the optimization of a single-family house envelope, using two objective functions, the life cycle primary energy use (LCE) and cost (LCC) [Ham 12]. On the other hand, Chien et al. (2012) conducted an multi-objective analysis on joining technologies based on two parameters: LCA and LCC [CHI 12]. A recent contribute was given by Ostermeyer et al. (2013) which propose a multidimensional Pareto optimization methodology using LCC and LCA [OST 13]. Table 2. 3 below summarize all the analysed studies.

Literature

Design Objectives

N° of obj.

Optimization method

Application field

Hyun et al. 1998Total utility work, rate of part usage and total setup cost3Multi Objective Genetic Algorithm (MOGA)Sequencing problemsAzapagic 1999Total production, costs and Global WarmingPotential3Multi-objective Linear Programming (MOLP)Chemical industryWright 2002Energy cost and Thermarl Disconfort2Multi-Objective Genetic Algorithm (MOGA)Building sectorBrown and Salcedo 2003Effectiveness (OMOE) and Costs (LCC)2Multi-Objective Genetic Optimization (MOGO)Naval ship DesignLiu et al. 2004Initial cost, design complexity and lifetime seismic damage cost3Multi-Objective Genetic Algorithm (MOGA)Structural systemWang et al. 2005LCC and LCEI2Multi-Objective Genetic Algorithm (MOGA)Building sectorWang et al. 2006LCC and LCEI2Multi-Objective Genetic Algorithm (MOGA)Floor shape (Building Sector)Fragiadakis et al. 2006Material weight and LCC2Evolution Strategies Multi Objective (ESMO)Structural systemVerbeeck andHens 2007LCC and LCA2Multi-Objective Genetic Algorithm (MOGA)Building sectorFrangopol and Liu 2007Condition, safety and LCC3Multi-Objective Genetic Algorithm (MOGA)Structural systemDeng et al. 2008LCC and LCA2Multi-Disciplinary optimization (MDO)Mechanical product designOkasha and Frangopol 2009Reliability, Redundancy and LCC3Non-dominated Sorting Genetic Algorithm (NSGA)Structural systemTuhus-Dubrow and Krarti (2010)LCC and energy use2Multi-Objective Genetic Algorithm (MOGA)Building sectorFrangopol 2011Condition, safety and LCC3Multi-Objective Genetic Algorithm (MOGA)Structural systemCerri 2011LCC and LCA2Non-dominated Sorting Genetic Algorithm (NSGA)Product DesignGanjidoost 2011LCC and LCA2Multi-Objective Linear Programming (MOLP)Building sectorAllacker 2012LCC and LCA2Multidimensional Pareto OptimizationBuilding sectorFlager et al. 2012LCC and carbon footprint2Multi Objective Genetic Algorithm (MOGA)Building sectorFesanghary et al. 2012LCC and CO2 emissions2Harmony search (HS) algorithmBuilding sectorHao 2012LCC, energy consumption and comfort ofindoor environmental quality3Nondominated Sorting Genetic Algorithm (NSGA)Building sectorChien et al. 2012LCC and LCA2Multi-Objective algorithm (MOA)Joining TechnologiesHamelin et al. LCC and LCE2Particle Swarm OptimizationBuilding sectorDeng et al. 2013LCC and LCA2Multi-Disciplinary optimization (MDO)Mechanical product designOstermeyer et alLCC and LCA2Multi-Dimensional Pareto OptimizationBuilding sectorTable 2. 3 Summary of relevant multi-object optimization models for LCC and LCA

Findings from review of previous multi-objective optimization model

After a systematic analysis of more than 50 papers it is possible to identify more or less 24 papers in which multi-objective optimization is applied involving LCC or LCA or performance or all of them. Many considerations can be done observing: design objective; optimization method; application field

Design objectives

The design objectives adopted by the previous studies can be divided in three main categories: costs, environmental impacts and performance. For cost is mainly used LCC because it include various form of cost incurred throughout the whole product lifecycle. Moreover, LCC is well suited to the economic evaluation of design alternatives that satisfy a required performance level but may have differing investment, operating, maintenance, or repair costs, and possibly different life spans [FUL 05]. In regard of environmental impacts, most of them are evaluated with LCA but in some researches it was used operational energy performance or LCEI as proxy. Compared to cost or to environmental impacts, frequently performance seems to be treated as a secondary concern and is significantly less considered as a design objective with the same level of importance to cost and environmental impact. Out of 24 studies reviewed merely 6 incorporated performance in the optimization process. Only Azapagic (1999) and Hao (2012) in their works considered a three objective optimization involving LCC, LCA and Performance. The majority of all other studies (70, 83%) take in account just the economic and environmental aspects. In term of number of objectives it is relevant point out that the 29, 17% of the studies regard three objective optimization model. The pie chart show the percentages of design object (Figure 2. 4). Figure 2. Design objectives percentages

Optimization methods

Several multi-objective optimization method can be identified from the previous studies analyzed. Over 60% of the papers adopt a Multi Objective Genetic Algorithm to optimize the considered problem. The left percentage is quite equally divided between other optimization techniques such as Multi-Disciplinary Optimization (8, 33%), Multi-Objective Linear Programming (8, 33%), Multi-Dimensional Pareto Optimization (8, 33%), Particle Swarm Optimization and Others techniques (12, 50%). This absolute majority in the use of MOGA it is not surprising, indeed genetic algorithm works with a population of points, it seems natural to use GAs in multiobjective optimization problems to capture a number of solutions simultaneously. Furthermore, different studies demonstrated that GA are the best and robust kind of evolutionary algorithm and they are more efficient than sequential search and other methods when over 10 parameters are involved [TUH 09]. Another consideration is that only 3 out of 15 papers adopting GA explain the kind of algorithm used. The pie chart shows the percentages mentioned before (Figure 2. 4). Figure Optimization methods percentages

Application field

Due to the increasing concern about green building and sustainable energy consumption the majority application of multi-objective optimization (50% of the analyzed studies) have been carried out in the building sector. Also in the structural system field there are many application of multi-objective optimization (16, 67%) mainly addressing to the maintenance and the safety of the infrastructure. Shortly after (12, 50%) there is the product design field. The left percentage consider other fields. The pie chart show the outlined percentages (Figure 2. 5). Figure 2. Application fields percentages

Limitation and deficiencies of previous optimization studies

Although the optimization models reviewed above could contribute to improve the product design decision making process, two major limitations are identified which would undermine their application in practice.

Incomplete set of design objective

Life Cycle Costs, Life Cycle Assessment and Performances are all important criteria in the product design decision making process, mainly in the early stage. However, the previous related optimization models reviewed so far consider only up to two design objectives from within the abovementioned three essential design objectives. As stated in the previous section, performances are largely neglected in previous relevant optimization models or they are often used as constraints. Therefore, most previous relevant optimization models did not reflect the whole picture in terms of the desired outcomes of product design.

Incomplete representation of LCA

In many studies Life Cycle Assessment is not completely conducted into the optimization models. This may be due to the difficult to obtain consistent and accurate data about environmental impacts and to the complexity of a complete assessment. This is lacking because considering few impacts only contributes partially to the overall LCA. Effectively, the goal of LCA is to compare the full range of environmental effects assignable to products and services in order to improve processes, support policy and provide a sound basis for informed decisions. Therefore, all the aspects are important dimensions in order to constituting a perfect LCA.

Shortage of studies in the product design field

Even though, LCC and LCA are methodologies born more that forty years ago and even if it is well-know that their integration and optimization are essential in the product design decision making process, nowadays there is still uncertain in their application. In effect, this statement is outlined from the lack of relevant studies optimizing together LCC, LCA and Performances. This may be triggered by the fact that it is possible carry out separate analysis for each methodology. But neglecting the integration and optimization lead to a loss of important information in the decision making, mainly regarding the trade-off between the costs, environmental aspects and performances.

Chapter summary

In this chapter has been reviewed the role, the integration and the optimization of LCC, LCA and performance in the product design decision making process. It has been discovered that optimization is seldom applied in practice despite its advantages in obtaining improved design solutions and presenting a broader picture of the whole design space. On the other hand, a series of multi-optimization models have been developed in academia. After a detailed and in-depth review of those optimization models, three major limitations are identified, namely incomplete set of design objectives, incomplete representation of LCA and shortage of studies in the product design field. This research study aims at bridging the identified research gap by developing an improved multi-objective optimization model in order to optimize the product design. In other words, the proposed model should take into account three design objectives: minimization of LCC, minimization of LCC, and maximization of Performances.