Lecture Notes in Management and Industrial Engineering

José Luis Ayuso Muñoz
José Luis Yagüe Blanco
Salvador F. Capuz-Rizo *Editors*

Project Management and Engineering Research, 2014

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Preface

The Spanish Association of Project Management and Engineering is pleased to issue this volume. It compiles a selection of the best papers presented at the 18th International Congress on Project Management and Engineering held in Alcañiz (Teruel). They are a good sample of the state of the art in the fields of project management and project engineering.

After having organized an annual Congress—first at the national and then at the international level—with an array of universities over the last 18 years, by the end of 2008, the AEIPRO Directive Board decided to introduce a two-step procedure to evaluate the papers presented. First, the Scientific Committee assess all the papers presented to select the approved ones to the Congress. After the conclusion and taking into account the chairman reports of the session, a second assessment is performed by a reduced Scientific Committee. We hope that the fruit of this process, this volume, contributes to the improvement of project engineering research and enhance the transfer of results to the job of project engineers and project managers.

The Spanish Association of Project Management and Engineering (Asociación Española de Dirección e Ingeniería de Proyectos—AEIPRO) is a nonprofit organization founded in 1992. It is an entity for the professionalization of project management and engineering with the following goals: to facilitate the association of scientists and professionals within the project management and engineering areas; to serve as a tool for improving communication and cooperation among these professionals; to improve experts' knowledge in the different fields of project management and engineering; to promote the best professional practices in these fields; to identify and define the needs that may arise in the everyday development of these activities; and finally, to adopt positions in order to orientate society when faced with differences in the fields of action. At present, it is the Spanish Association Member of International Project Management Association (IPMA), an international association that brings together more than 48,000 project management professionals and researchers from 59 countries.

The papers presented in this book, address methods, techniques, studies and applications to project management and all the project engineering areas. The contributions have been arranged in seven chapters:

- Project Management
- Civil engineering, urban planning, building and architecture
- Product and Process Engineering and Industrial Design
- Environmental engineering and natural resource management
- Energy efficiency and renewable energy
- Rural development and development co-operation projects
- Training in project engineering

We want acknowledge our gratitude to all the contributors and reviewers.

Valencia, Spain
October 2015

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Project Management

Critical Success Factors For Construction Projects

Behzad Esmaeili, Eugenio Pellicer and Keith Robert Molenaar

Abstract The literature demonstrates a lack of consensus and consistency to identify critical success factors (CSFs) for different construction operations. Therefore, the objectives of the study are to: (1) identify and categorize CSFs from literature; (2) examine the limitations of the current practices; and (3) recommend future studies. CSFs from the existing literature were categorized according to their emphasis on project outcomes, delivery methods, project types, and partnering processes. Upper management support, commitment, constructability reviews, teamwork, communication, and building trusts emerged as they shared key elements of success in most construction activities. Previous studies' major limitation lays in the emphasis on experts' subjective prioritization of CSFs and the limited number of empirical studies. The results of the study also demonstrate that there is a great potential for investigating CSFs for emerging delivery methods, and for exploring the causality relationships between CSFs and project success.

Keywords Success factors · Project delivery methods · Partnering

1 Introduction

Critical success factors (CSFs) in the context of project management were first defined by Rockart (1982) as the limited number of factors that should be satisfied to ensure successful completion of a project. Since then, a considerable amount of research has been focused on exploring CSFs for construction projects (e.g. Belassi

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and Tukel 1996; Li et al. 2005). These studies gained attention, because identifying CSFs helps practitioners allocate their limited resources to a manageable number of factors that contribute to project success. Although researchers often develop metrics for CSFs—such as mutual trust, effective communication, and adequacy of resource-, there is lack of consensus among researchers regarding the most critical factors, and there is little consistency in their definition and use of language.

Therefore, exploring the evolution pattern of CSFs in the construction literature and predicting the future trajectories would be rewarding. To answer this knowledge gap, the current literature study was conducted to: (1) identify and categorize CSFs according to different project outcomes, delivery methods, project types, and partnering processes; (2) examine the limitations of the current practices; and (3) provide suggestions for future potential studies. To achieve these objectives, a large number of research papers were reviewed; their salient results are summarized in the following sections. The results of the study are the first step towards developing universal CSFs for construction projects to help practitioners create high performance teams.

2 CSF for Different Project Outcomes

Each project team member might pursue different or even contradictory objectives in a project. For example, a contractor may consider construction speed and profitability as the most important measures of success, while an owner may emphasize on-budget completion or quality of construction. These conflicting views of success can result in poor overall project performance if expectations are not communicated. In response to these divergent priorities, most of the previous literature identified CSFs for shared objectives among different team members; these factors included cost, time, and quality.

In one of the early studies, Jaselskis and Ashley (1991) investigated different key success factors that assist project managers to allocate their limited resources in such a way as to achieve a high level of construction performance. After analyzing data from 75 construction projects, they found that the following factors improve the likelihood of achieving outstanding project performance: reducing team turnover, providing a constructability program for contractor organization, and increasing number of construction control meetings for the contractor organization. Furthermore, they found that the success factors affected project outcomes differently. For instance, "reducing team turnover" had more impact on improving budget performance than emphasizing schedule or overall project performance.

In another study, Chua et al. (1999) identified CSFs for different project objectives, including budget, schedule, and quality. They identified sixty-seven factors and grouped them into four main categories: project characteristics, contractual agreements, project participants, and interactive processes. Chua et al. (1999) then distributed a survey questionnaire among experienced practitioners to make pairwise comparisons and determine the relative importance of the various CSFs. They found that regardless of project objective, adequacy of plans, specifications, and constructability are the most important factors characterizing successful projects.

In one of the empirical studies, Cooke-Davies (2002) conducted a detailed analysis on 136 projects executed between 1994 and 2000 and identified 12 factors that were critical to project success. They found that although in some cases schedule delay and cost escalation correlated in an individual project, only a small amount of the cost escalation was accounted for by schedule delay. Their results indicated that the following practices correlate with on-time performance: adequacy of company-wide education on the concepts of risk management; maturity of an organization's processes for assigning ownership of risks; adequacy with which a visible risk registers is maintained; adequacy of an up-to-date risk management plan; adequacy of documentation regarding organizational responsibilities on the project; and keeping the project (or project stage duration) less than 3 years, with benefits evident among projects closer to 1 year in length. On the other hand, the following practices correlate with on-cost performance: only allowing changes to scope through an established scope-change control process; and maintaining the integrity of the performance measurement baseline. In addition to the above mentioned factors that contributed to project management success, the existence of an effective benefits delivery and management process involving the mutual co-operation of project management and line management functions were critical for overall project success.

3 CSFs for Different Project Delivery Methods

Project delivery systems determine the sequencing of design, procurement, and construction, and define the roles and responsibilities of the parties involved in a project. Common delivery methods include design-bid-build (DBB), construction management at risk (CMR), design-build (DB). However, some governments' financial constraints paved the way for innovative methods of development and the financing of public facilities and services via the private sector. Two prominent examples of such methods that have been adopted extensively across the globe are build-operate-transfer (BOT), and public-private-partnership (PPP). A summary of CSFs for different project delivery methods is provided below.

3.1 Common Delivery Methods (DBB, CMR, and DB)

DBB is the traditional project delivery method in the US characterized by two separate contracts for design and construction (Bearup et al. 2007). In this method, the owner hires a designer to provide complete design documents and then selects a contractor based upon a fixed price bid to build the project according to the completed drawings (Touran et al. 2009). One of the disadvantages of this delivery method is that the owner has to contract two different entities, and the construction cannot be started until the design is complete. To overcome this limitation, CMR evolved from the traditional project delivery system as a method to obtain significant constructability input during the design phase of the project by overlapping the design and construction phases (Bearup et al. 2007). While the CMR approach provides some benefits for overlapping design and construction, the owner still has to manage two separate contracts. To address this limitation, DB delivery system was introduced to help the owner contract a single entity. In fact, any delivery method in which one party is held responsible for the design and construction services is called DB (Songer 1992).

Due to its numerous advantages, DB became a popular delivery method in the past decades, with several studies conducted to facilitate successful completion of these projects. For example, Chan et al. (2001) investigated public sector DB projects to identify a set of project success factors and to determine their relative importance. They analyzed survey responses from 53 participants using multiple statistical techniques, such as factor analysis, stepwise multiple regression, two independent sample t-test, and bivariate correlation. Six project success factors were extracted, including project team commitment, contractors' competencies, risk and reliability assessment, client's competencies, end-users' needs, and constraints imposed by end-users. They found that project team commitment, and contractor's and client's competencies are the most influential factors for project success. The results of the study suggested practitioners focus on team work and partnering to make a project successful.

In another study, Ling et al. (2004) collected empirical data from 87 DBB and DB projects to search for explanatory variables that significantly affect project performance. They catalogued 59 potential factors affecting project performance (e.g. cost growth) and conducted multivariate data analysis to investigate their underlying relationship. It was found that construction speed of DBB projects is determined by gross floor area and the adequacy of contractor's plant and equipment; however, for DB projects, the extent to which contract period is allowed to vary during bid evaluation is more crucial. In a similar study, Lam et al. (2008) investigated determinants of successful DB projects to set a benchmark for comparing project performance. They developed a project success index and distributed a questionnaire among DB participants in the Hong Kong construction industry to investigate the casual relationship between the project success index and the key project performance indicators of time, cost, quality, and functionality. Then, factor analysis and multiple regressions were used to analyze Point and followed; they found that the project's nature, the effective project management action, and the adoption of innovative management approaches are the most critical success factors for DB projects. It is important to note that the nature of the project is determined by the extent of contractor's input, attractiveness of the project, and the complexity of the project. On the other hand, project management actions can be described by up-front planning efforts, effectiveness of communication, control and management systems, and organizational structure. Furthermore, it was suggested that adopting innovative management approaches—such as value management and partnering- can increase the chance of success in a DB project.

3.2 Build-Operate-Transfer (BOT)

In a BOT contract, the private sector is financing the project and furnishing design and construction. More importantly, after completion of a project, the private sector manages and operates the facility for a specified concession period and then transfers the asset to the host government. While, the BOT model of project development provided tremendous opportunities for both governments and contractors, winning a BOT contract is not easy and the negotiation process is complex, time-consuming, and expensive business (Tiong 1996). Therefore, several studies were conducted to shed light on the road to winning a BOT contract. For example, Tiong et al. (1992) conducted an in-depth analysis of nine major BOT projects and interviewed their entrepreneurs, project sponsors, and government officials. They identified six CSFs in winning BOT contracts: entrepreneurship and leadership, right project identification, strength of the consortium, technical solution advantage, financial package differentiation; and differentiation in guarantees. In a follow up study, Tiong (1996) quantified the relative importance of different factors and found that the strength of consortium and financial package differentiation are the most important factors in winning a BOT tender.

3.3 Public-Private-Partnership (PPP)

PPP, or P3, is defined as a contractual agreement between the public agency and a private entity that enables the private sector to finance and deliver public projects (Ke et al. 2009). Some of the perceived benefits of PPP projects for the public sector are: enhanced government capacity; innovation in delivering project services; reduction in time and cost of project delivery; and transferring the majority of the risk to a private party to secure taxpayers' value (Li et al. 2005). Based on the allocation of resources, risks, and rewards, different types of PPP projects have emerged (Li et al. 2005). As PPP projects are characterized by a broad range of risks, uncertainties, and the involvement of multiple participants, it is important to develop an efficient procurement protocol to improve practices in these projects (Zhang 2005).

In one of the prominent studies, Li et al. (2005), identified 18 CSFs for PPPs and evaluated their relative significance in the United Kingdom. By obtaining the ranking of perceived importance of different CSFs, the following factors emerged as being the most important considerations: (1) a strong private consortium; (2) appropriate risk allocation; and (3) the available financial market. They also conducted factor analysis and grouped CSFs into effective procurement, project implementability, government guarantee, and favorable economic conditions. Likewise, Zhang (2005) identified 47 critical success factors for PPPs and categorized them into five groups: a favorable investment environment, economic viability, reliable concessionaire consortium with strong technical strength, sound

Table 1 Summary of CSFs for different project delivery methods

Categories	Critical success factors	
Common delivery methods (DBB, DB and CMR)	Ling et al. (2004)	• Adequacy of contractor's plant and equipment
	Chan et al. (2001)	• Project team commitment
		• Contractor's competencies
		• Risk and reliability assessment
		• Client's competencies
		• End-users' needs
		• Constraints imposed by end-users
	Ling et al. (2004)	• The extent to which contract period is allowed to vary during bid evaluation
	Lam et al. (2008)	• Project nature
		• Effective project management action
		• Adoption of innovative management approaches
Build-operate-transfer (BOT)	Tiong et al. (1992), and Tiong (1996)	• Entrepreneurship and leadership
		• Right project identification
		• Strength of the consortium
		• Technical solution advantage
		• Financial package differentiation
		• Differentiation in guarantees
Public-private-partnership (PPP)	Li et al. (2005)	• A strong private consortium
		• Appropriate risk allocation
		• Available financial market
	Zhang (2005)	• Favorable investment environment
		• Economic viability
		• Reliable concessionaire consortium with strong technical strength
		• Sound financial package
		• Appropriate risk allocation via contractual arrangements

financial packages, and appropriate risk allocation via reliable contractual arrangements. He also measured the relative significance of sub factors by distributing a worldwide questionnaire survey. A summary of CSFs different project delivery methods is shown in Table 1.

While the growing market of construction projects in China absorbed a large number of international firms, there was no robust method for predicting the outcome of these projects. To address this gap in knowledge, Ling et al. (2008) conducted a study to predict project success in China based upon the project management practices implemented by the company. They obtained data from 33 projects to identify different project management (PM) practices as explanatory variables of each project's performance. They also used multiple linear regressions to develop five models to predict the probability of project success. The results indicated that a firm's response to perceived change orders is the most important PM practice. In addition, they found that the overall project performance was largely affected by upstream activities, such as managing project scope. The main contribution of the model is to help project personnel to predict project success potential based upon the project management practices used. Lu et al. (2008) used a similar approach to identify CSFs for competitiveness of contractors in China. The relative importance of factors was also obtained thorough survey and questionnaire. The top three factors proved to be a bidding strategy, an explicit competitive strategy, and relationships with government departments.

4 CSFs for Partnering Process

A construction project typically requires collaboration between multiple parties with diverse organizational objectives and culture. It is proven that a clash of values and the existence of complex relationships between team members have an impact on project performance (Anvuur and Kumaraswamy 2007). For example, little cooperation, lack of trust, and inefficient communication can cause adversarial relationships between parties and lead to project delays, difficulty in resolving claims, cost overruns, litigation, and a win-lose climate (Moore et al. 1992). One of the widely practiced management strategies intended to improve interorganizational relations is partnering.

Partnering is defined as a cooperative strategy that aims to bridge organizational boundaries and create an environment in which team members can openly interact and perform (Crowley and Karim 1995). The fundamental principles of partnering are commitment, trust, respect, communication, employee involvement, and equality (Construction Industry Institute [CII] 1991; Cowan et al. 1992; Sanders and Moore 1992; Uher 1999). Indeed, the partnering process is designed to transform the traditional and adversarial approach into a highly communicative network of construction parties (Cheng and Li 2002). It provides several benefits to project and team members, such as an effective framework for conflict resolution, improved communications, reduced litigation, lower risk of cost overruns and delays, and increased opportunities for innovation (Abudayyeh 1994; Harback et al. 1994; De Vilbiss and Leonard 2000; Black et al. 2000). Partnering makes all of these benefits possible by re-orientating project participants toward a "win-win" approach and by fostering a teamwork environment.

Several studies examined the best way of implementing partnering. For example, Cheng et al. (2000) developed a framework to identify CSFs that contribute to the successful use of partnering in projects. The authors claimed that to have an effective partnering, there should be specific management skills and contextual characteristics. While management skills are necessary to initiate, form, and facilitate interorganizational relationships, one should prepare a favorable context before starting the partnering process. After reviewing literature, effective communication and conflict resolution were considered as the critical management skills, and adequate resources, management support, mutual trust, long term commitment, coordination, and creativity were classified as critical contextual factors. The authors also suggested a list of measures to monitor and control partnering performance by targeting both short- and long-term objectives. Short-term objectives —such as cost variation and the rejection of work—were mainly related to an individual project while long-term goals were concerned with the perceived satisfaction of partners' expectations.

Black et al. (2000) analyzed several companies with and without partnering experience to investigate the importance of CSFs toward partnering success. They obtained the opinion of clients, consultants, and contractors in the UK regarding the success factors and benefits of partnering. They found that the following requirements should be met to implement partnering successfully: trust, communication, commitment, a clear understanding of roles, and a consistent and flexible attitude. The results also indicated that clients and contractors are more supportive towards the partnering process than consultants.

Cheng and Li (2002) took a different approach by identifying CSFs for different stages of partnering: formation, application, and reactivation. The factors were prioritized using an analytical hierarchy process. The results indicated that some of the CSFs influence the whole partnering process, while there are some CSFs for individual process stages. The common CSFs for whole partnering process are top management support, open communication, effective coordination, and mutual trust; CSFs at the stage of partnering formation are team building, facilitator, and partnering agreement; CSFs of partnering application are joint problem solving, adequate resources, and partnering goals' achievement. Finally, partnering experience, continuous improvement, learning climate, and long-term commitment are important in the partnering reactivation phase. The study is creative in developing a customized CSFs model; however, due to the low number of responses (9 filled-in questionnaires), it should be considered as an exploratory study.

One of the issues that can affect the partnering process is cultural differences (Cheng and Li 2002). Therefore, as adopting partnering becomes a common practice across the world, researchers attempt to identify partnering CSFs based upon local characteristics for a specific country. For example, to understand the ingredients of successful partnering in the Hong Kong construction industry, Chan et al. (2004) identified critical success factors for partnering projects by obtaining the opinions of various parties, such as clients, contractors and consultants. They used factor analysis and multiple regressions to investigate the relationship between the perception of partnering success and a set of success factors. The results showed the following requirements are necessary for successful partnering: the establishment and communication of a conflict resolution strategy, a willingness to share resources among project participants, a clear definition of responsibilities, a commitment to a win-win attitude, and regular monitoring of partnering process.

Table 2 Summary of CSFs for partnering process

Studies	Critical success factors		
Cheng et al. (2000)	*Management skills*	*Contextual factors*	
	• Effective communication • Conflict resolution	• Adequate resources • Management support • Mutual trust • Long term commitment • Coordination • Creativity	
Black et al. (2000)	• Trust • Communication • Commitment, a clear understanding of roles • Consistency and flexible attitude		
Cheng and Li (2002)	*Formation*	*Application*	*Reactivation*
	• Top management support • Mutual trust • Open communication • Effective coordination • Facilitator • Team building • Partnering agreement	• Top management support • Mutual trust • Open communication • Effective coordination • Joint problem solving • Partnering goals' achievement • Adequate resources • Creativity • Workshops	• Top management support • Mutual trust • Open communication • Effective coordination • Long-term commitment • Continuous improvement • Learning climate • Partnering experience • Joint problem solving • Adequate resources • Workshops
Chan et al. (2004)	• Establishment and communication of a conflict resolution strategy • A willingness to share resources among project participants • A clear definition of responsibilities • A commitment to a win-win attitude • Regular monitoring of partnering process		

A summary of CSFs for the partnering process is provided in Table 2. It should be noted that only papers that focused on critical factors contributing to successful implementation of partnering were reviewed. There are several studies that examined the impact of partnering on projects success (e.g. Larson 1995) that are out of scope of this study.

5 Conclusions

Success in a construction project is repeatable, and there is a great value in developing a protocol to improve practices in construction activities. The identification of CSFs can furnish project participants with an indicator to achieve success in delivering a project or implementing a process. Moreover, CSFs can provide participants with a focus of what they should be aware of in order to ensure the success of a project. Such an improved understanding can be exploited by project managers to select efficient strategies to alleviate the root causes of poor performance.

To shed light on current practices, this study conducted a comprehensive investigation of literature on CSFs. The results of this study contribute to the practice by providing a list of CSFs for various construction operations, and academia can benefit from identifying the potential topics for future studies. It was found that upper management support, commitment, constructability reviews, teamwork, communication, and building trust are the key elements of success in most construction projects. While the contribution of previous studies in the area of CSFs is significant, there are several limitations related to these studies. First, most of the previous studies rely on obtaining ratings from experts; providing empirical evidence based upon completed projects is rare. Since experts' judgment is subjected to various cognitive biases, the results can be misleading (Tversky and Kahneman 1974). Second, most of CSFs identified in previous literature (e.g. trust) are subjective, and it is very difficult to measure them during a real construction operation.

There are several research topics related to CSFs that can be further investigated. For example, new project delivery systems, such as integrated project delivery (IPD), are gaining traction in recent years, and determining CSFs for them is rewarding. Kent and Becerik-Gerber (2010) described the common principals of IPD, including a multiparty agreement, shared risk and rewards, and early involvement of all parties. Establishing these principles is not an easy task, and finding a concise number of factors that should be given special and continued attention to increase the chances of a successful outcome is important. Furthermore, one may explore the casual relationships between CSFs and project success based upon empirical evidence.

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Implementation and Evolution of the Critical Chain Method: A Case Study

U. Apaolaza and A. Lizarralde

Abstract The Critical Chain Project Management (CCPM) method has been implemented in a wide variety of industries, activities and countries. This article is based on the implementation of this method in two different units of the same company which designs, develops and produces high-tech parts. Even if it is based on the implementation process and its results, the scope exceeds this context. The analysis is made with a time perspective, considering not only the implementation but also the evolution following its completion. As a result, two different sides can be highlighted: the first one concerns the outcomes achieved in each case as a consequence of the implementation of the method, and the second one is related to the key aspects identified in the implementation processes—in particular the success factors. The comparative analysis regarding the results achieved in both cases, in a time period that goes beyond the implementation timeframe, is of special interest. The findings of this work lead to some new aspects concerning the method, which require further research.

Keywords CCPM · Critical chain · Project management · TOC · Theory of constraints

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1 Introduction

Project Management (PM) is a discipline whose origin dates back to the mid-20th century (Archibald 1987), appearing to have reached maturity (Bredillet 2010). Its growth and development were particularly steep during the second half of the last century, as a result of the growing interest in projects and their management (Kloppenborg and Opfer 2002). Indeed, many authors agree with this idea due to reasons such as the fact that projects are the means by which strategies are performed (Marucheck et al. 1990), new products are developed and launched (Cook 1998), or the innovation strategy of a company is implemented and developed (Tatikonda and Rosenthal 2000). Furthermore, due to the progressive "projectification" of work, the use of projects seems to continuously grow in the future (Stoneburner 1999; Kloppenborg and Opfer 2002), confirming the relevance of PM at present.

Considering the above, together with the increasing trend towards both, the use of PM approaches and the need to address real world problems, several perspectives and patterns have arisen in recent years (Goldratt 1997; Beck et al. 2001), acquiring great relevance (Pinto 2002). The underlying idea here is that PM can be a competitive advantage for companies if it is properly implemented. This way, they could increase their chances of survival, or even reach a better competitive position.

This paper is practice-based research about the implementation of one of these methods, Critical Chain, in a company that having tried different approaches unsuccessfully, decided to implement it to solve the problems related to the management of projects and resources in two R+D+i units. In particular, it covers the results and findings achieved during a three-year period that followed the implementation process carried out in both units.

1.1 Background of the Company

The company analyzed in this enquiry develops and manufactures capital goods for machine automation and control. The 560 people workforce of the company is organized into two units, each one being responsible for one product line. They export more than 80 % of their production globally, and in recent years they have diversified their activity towards other sectors. But despite this international expansion effort, this company is much smaller than those leading this industry.

In this context PM performance is a key factor in achieving a competitive advantage or simply surviving, and a proper use of their capacity (resources) becomes essential. Additionally, since the market is evolving continuously they are forced to constantly upgrade their products and to broaden their catalogue by developing new products in order to remain competitive. These features lead to frequent changes and new needs such as technological developments and new trends, thereby causing the portfolio to be very dynamic, and requiring fast responses.

There were some attempts in the past so as to get an approach capable of dealing with this issue, but all of them were unsuccessful. Consequently, there was a lack of information from a managerial perspective, creating difficulties in managing the system properly. In addition, some kind of rejection against new improvement attempts turned up among the workers, as a consequence of the time and efforts wasted before. As a first step a profound reengineering of the new product development process was carried out, defining the framework for projects. Then, it became obvious again that it was necessary to manage projects efficiently. Taking all this into account, the company decided to try the Critical Chain method.

1.2 The Critical Chain Project Management Approach

CCPM is a method for managing projects developed by Goldratt (1997), founded on the principles of his Theory of Constraints—TOC (Goldratt 1992). Since it was published, it has continuously evolved on the basis of an intensive usage by practitioners in real-world environments, leading to a large number of publications including implementation methodologies and success stories, among others (Leach 2005; Srinivasan et al. 2007; Gupta 2010). The main features of this CCPM can be summarized as follows: firstly, it assumes that uncertainty exists and that it cannot be avoided, even if it can be managed. Secondly, the method takes into account the impact of human behavior on projects. Finally, it addresses both single-project and multi-project management.

According to Execution Management approach, "*the key to good execution is not detailed planning and control, but coordination of execution priorities across the organization*" (Gupta 2010). This implies implementing "Three Rules", the Execution Management System and the Active Role of Senior Management, as briefly described below.

Implementation of the Three Rules:
The Threes Rules are Buffering, Pipelining and Buffer Management. Buffering consists of creating project plans according to CCPM, so as to dampen deviations and prevent project delays by using buffers. The aim of Pipelining is to stagger the projects taking into account resource availabilities, deadlines and global priorities. Finally, through Buffer Management the system looks for a better performance in the operative level by following task priorities and preventing the waste buffers.

Execution Management System:
It means synchronizing the whole system consistently with the three rules. Key aspects:

- Operational Goals and Measurements: aggressive operational goals (schedules) and measurements so as to promote execution according to synchronized priorities and early warning signals.

- Management Policies and Processes: needed to, respectively, enforce the new rules of Critical Chain and translate these rules into understandable decisions and actions.
- Execution Oriented Project Schedules: suitable for execution and control according to CCPM.
- PM Information System: the means to integrate roles, information and decisions/actions. The software used in this case was Concerto.

Active Role of Senior Management:
The direct involvement of top management is a key success factor. As the implementation of CCPM implies a profound change, the supervision and engagement is essential, especially until the method has been interiorized by staff. In addition, only top management can proactively identify and eliminate policy obstacles. Therefore, they must be involved in the implementation.

2 Aim, Methodology and Structure of the Research

In spite of the maturity reached by PM, as stated in the introduction, some authors claim that PM research is still in its early stages (Sauser et al. 2009), and it calls for a different approach to the one provided by the traditional PM research (Ivory and Alderman 2005; Cicmil 2006). Investigation going beyond existing PM models and more focused on the practice is considered very important in order to achieve a deeper understanding of PM (Blomquist et al. 2010). Additionally, O'Neal et al. (2006) revealed that there is a gap between the professional (dominant) and the academic worlds, as most of the PM articles have been published in practitioners' journals.

Under these circumstances, real-time case studies and project organization studies are of particular interest. In this case the focus is not on the implementation and its results, but on the post-implementation period and the comparison between two similar organizations (units). Considering the above, the aim of this research is to:

1. Expound a real-world experience.
2. Draw valuable findings and conclusions for their use in practice.
3. Contribute to bridging the gap between the academic world and the practitioners' reality.

As stated earlier, the starting point for this research was given by the situation once the implementation project was completed, and this study is limited to the R+D+i units of the company, involving 115 people.

Figure 1 summarizes the process followed while carrying out the study. The methodology used is based on case study research (Gummesson 2000; Yin 2009) and combines different approaches: starting from the initial results of the implementation, the research addresses the evolution of both units during a three-year

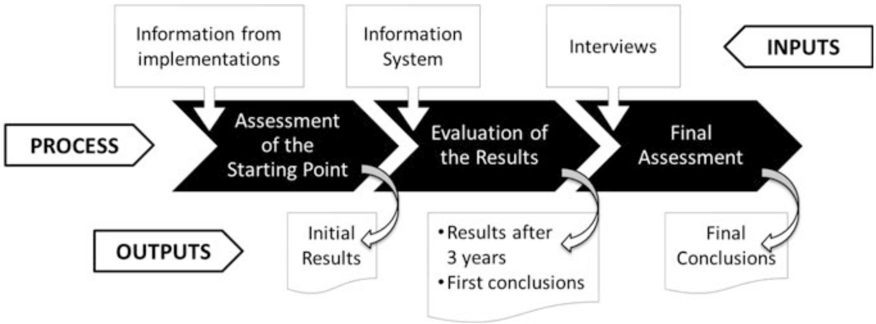

Fig. 1 Research methodology

period. This involves observation and analysis of (i) the results achieved, (ii) the evolution of the method and its performance, and (iii) the behaviour of those directly involved in the management of projects. Since different kinds of information were required for this purpose, diverse sources were used: information from the implementation process, data provided by the information system and formal and informal interviews conducted with employees involved in projects. The stages of the research are detailed in depth in Sect. 1.3.

3 Research: Stages, Results and Performance Assessment

3.1 Assessment of the Starting Point

Both researchers were directly involved as implementers in that process. So, all the information collected during the project was available for this purpose. This information included files and records, reports, working-papers, interviews, meeting minutes, etc., which is the foundation of the stage 1 of this research.

The situation at the beginning of project can be summarized as follows: inexistence of a suitable PM methodology and a perceived need for change. It also was found that CCPM was a completely unknown method to almost everybody in the company. Thus, the analysis of the system so as to understand its needs and limitations became even more important, including the features of both projects and resources (Apaolaza 2009). In this way an initial analysis was performed, and as a result valuable information regarding the business and the company was gathered. A summary of the main features of the context are provided below:

- Multi-project environment: different projects performing simultaneously, sharing (and often competing for) common and limited resources.
- Very specialized resources, low polyvalence due to the long time required to get enough experience, and extreme difficulties to get more resources within a short period of time when additional capacity is required.

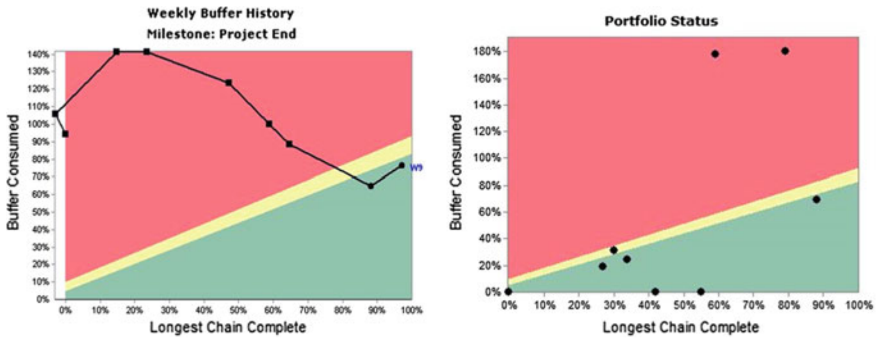

Fig. 2 Examples of results achieved during the implementation. *Left* Progress of the project during the pilot test. *Right* Project portfolio in Unit 2

- Uncertainty: by its very nature, uncertainty is inherent to these projects, thereby making their management more difficult (Shenhar and Dvir 1996).

The implementation plan was constructed and accepted by all the parties involved, completing the buy-in. The plan was made up of three main stages: a pilot test to be run in Unit 1 involving one project, the implementation in Unit 1 (conditioned to the results obtained in the pilot test), and the implementation in Unit 2.

The pilot test was carried out through a representative project, over a three-month period. Figure 2 (left) depicts the evolution of the project, completed on time as a consequence of the decisions made based on the visibility and information provided by the method. This brought with it the release of the second stage, involving the whole Unit 1.

The implementation of the method in Unit 1 lasted 4 months, requiring a customization and adapting the generic rules to that specific context. It resulted in the development of a suitable management model that included workload (projects), capacity (resources) and roles and responsibilities. Additionally, the integration of the model, the planning process and the execution management needed some other ingredients. Thus, two specific forums were created: the project tracking committee and the project launching committee. While the project launching committee was responsible for the management of the project portfolio, the aim of the project tracking committee was the monitoring and control of the performing projects.

Despite the success of the pilot project, the implementation in Unit 1 did not progress as expected. Even though an agreement was reached in the first stage, some reluctance to change arose as a consequence of the time and efforts wasted in previous attempts. This lack of commitment led to a misalignment between needs and behaviors, causing the results initially achieved in the pilot test not to be expanded to other projects.

Finally, the implementation in Unit 2 was performed similarly but started later than the previous stage and overlapped with it. Surprisingly, the results achieved were good, even though a pilot test was not carried out there. As shown in Fig. 2 (right), most of the projects progressed well, better than in the past, thereby creating the impression that the method was suitable for that environment. Moreover, they were aware at all times of delays in some projects. As a result, when necessary they consciously decided which projects would be delayed, when, and for how long. Nevertheless, further research was needed so as to confirm or discard these findings and deepen in the causes and key factors that led to such different results.

In view of the very different results obtained an analysis of the whole project was carried out, covering both units. The report based on this analysis was then presented to the senior management of the company, including managers from both units. There was an agreement on the diagnostic, and the recommendations were very welcomed. In summary, the following was the content of the report:

Unit 2's success not only did show that the method was applicable to this context, but it also provided significant advantages. Likewise, there were no significant differences between both units to conclude that it could only work in Unit 2.

Daily reporting and task performance according to priorities were keys to success. The levels achieved were high in Unit 2 and low in Unit 1, which was a flaw because of its direct consequences over the PM system: lack of visibility, misalignment with priorities, low resource and project performance. Instead, this was considered to be one of the main causes of success of Unit 2.

The engagement of the managers in the project is another fundamental pillar. Their involvement was high in Unit 2, but the commitment of certain managers in Unit 1 was insufficient. This fact would probably bring negative implications over the behavior of the workers, due to the impact of the poor results over the morale of the staff. As a result, the following was recommended:

1. Correct misaligned behaviors in Unit 1, starting with managers
2. Strengthen the performance of the information system, mainly in Unit 1
3. Expand the method to other parts of the company.

3.2 Evaluation of the Results

In order to get a better understanding of the implementation and use of the method, the results must be analyzed from different points of view. As both units work in very similar contexts and conditions, their performance in this period can be compared. Thus, this section summarizes the main quantitative and qualitative achievements reached by each unit along this time frame, including a comparison between these results.

3.2.1 Quantitative Results

The results achieved once the implementation was completed in Unit 2 can be summarized as follows: more projects completed on time and by time unit, shorter lead times, and dramatic reduction of terminated or postponed projects. On the

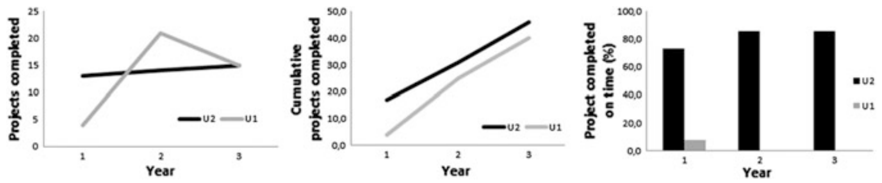

Fig. 3 Comparative results in 3 years

contrary, even if the context was very similar in both units, none of these results was achieved by Unit 1, achieving only some minor improvements.

- Amount of projects completed in the first year (Fig. 3, left): although it was expected that Unit 1 would complete more projects than Unit 2 due to the fact that it was bigger, having implemented the method before, it only completed 4 projects, while Unit 2 finished 13 projects.
- Evolution of performance for the following years (Fig. 3, center): it remained steady for Unit 2. On the other hand Unit 1 seemed to have improved its performance hugely in the second year, but it decreased again in the third year, going below the performance of Unit 2. The vast increase of completed projects happened in Unit 1 during the second year was due to the concurrence of lots of delayed that were still performing projects. This fact was proven during the third year, setting a new decreasing trend that lasted even in the first months of the fourth year.
- Amount of projects completed on time (Fig. 3, right): according to the criteria stated by the company, 90 % of the projects were completed on time in Unit 2 while almost no projects were delivered on time in Unit 1. Besides, delays regarding Unit 2 were of days or weeks at the worst, whereas in Unit 1 they reached months or even more than one year.

The results achieved by Unit 2 go beyond what Fig. 3 shows. By focusing resources in those high priority projects and according to the available capacity, the use of resources is improved, increasing efficiency and preventing resource assignment to low priority or urgency projects. Additionally, those projects terminated or postponed consume capacity which may have been necessary in other projects, implying a poor resource usage. The performance according to CCPM led Unit 2 to finish all the projects launched without any termination or postposition, thereby improving the productivity also from this perspective. Again, the results in Unit 1 were worse despite the fact that planning was done similarly in both units. The awful execution management caused some projects to be abandoned due to the delay accumulated, performing below its potential.

3.2.2 Qualitative Results: Overall Improvement of PM

This section gathers the most important results achieved regarding the qualitative side, due to their impact over the quantitative results. Although the implementation process was almost the same in both units, the maturity and results reached by them were very different. This fact led to the conclusion that only Unit 2 had properly implemented the method. Indeed, they remained very close to execution and were capable of reacting fast, making decisions aligned with the company's priorities and according to the current situation. The key for this was the coherent combination of visibility, flexibility and alignment at all levels within the organization, as explained below:

Visibility

Achieved in the early stages of the implementation, it was progressively improved as the maturity of the company was growing. It gave timely and accessible information about the different sides of the project environment, providing the company with the capacity of identifying deviations when they were happening, analyzing problems as soon as possible, and making decisions when necessary. It was the basis for decision making, and this global view was composed of different perspectives depending on the aspect to be observed (e.g. tasks, project progress, portfolio status, etc.). This was supported by the comments of some participants when asked if the method was helpful for the on-time completion of the pilot project, such as "*It helps to focus*" or "*It has forced us to react*".

The key here is to be aware that when used properly visibility may be an advantage. But it must be underlined that even if visibility is a necessary condition for improvement, it is not sufficient to achieve good results: it allows identifying deviations early, but taking advantage of this also requires decisions and actions. Figure 4 shows an example of such an opportunity provided by early warnings. This was the main difference between Unit 1 and Unit 2: while Unit 2 used visibility to manage projects and resources from a global perspective, Unit 1 only used visibility to know what the situation of individual projects was. Thus, the quality of the information was not good enough, causing the visibility provided by the information system to be inaccurate, leading to late and bad decisions.

Flexibility and Strategy-Projects-Resources Alignment

Visibility was also the base of other improvements. For example, when taking visibility and priorities into account, decisions regarding resources became easier. This information enabled the managers to make decisions aligned with the global priorities, ensuring that resources were always working on the right tasks. In other words, the system was flexible or capable of adapting fast to the real needs given by both, global priorities and current conditions.

As projects lasted for months or even years as well as being ever-changing, fast adaptation to reality was essential. In particular, aspects such as information accuracy and updating frequency determined the potential of the system to identify problems and react fast. For instance, portfolio management required information

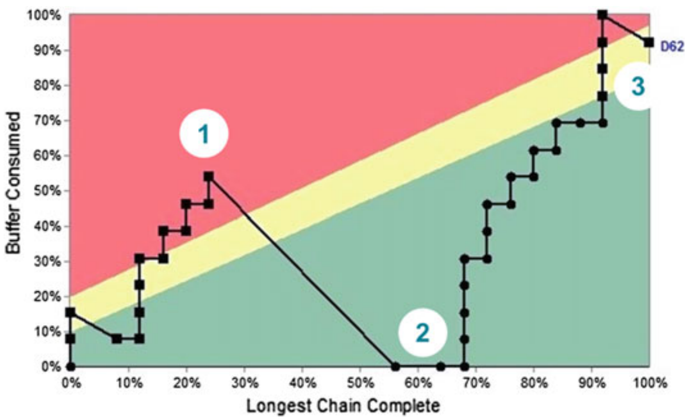

Fig. 4 Example of the evolution of one project reacting to make up the delay: the warning provided by the software (*1*) led to take actions to get back on track (*2*). As a result, the project was delivered on time (*3*)

related to project and resource status, and analysis and decisions related to this were normally made on a monthly basis, but it was also necessary whenever a new project was to be introduced in the system. Instead, single PM had to be closer to execution. In this context the duration of tasks could be shorter than one week. Therefore, task management was better made on a daily basis, requiring a daily task performance report according to CCPM as well. As a result, the use of resources and the project flow were improved.

Thus, the management of the planning and execution of tasks, projects and resources, both in the short and the long term became essential to manage the system consistently. The use of this information allowed planning and launching projects properly staggered, coherently with the resources available and aligned with the company's priorities. This approach was also used when new decisions were needed, for example due to changes in dates or priorities, or when new projects had to be introduced. Regarding execution, visibility was even more important, especially on the day-to-day basis where problems such as unbalanced resources, delays in programmed tasks' starting dates or variations in deadlines arose require fast responses. To this end, it was vital to have timely (daily) and updated information about the status of projects and tasks so as to allow the resource managers to keep their resources focused in the right tasks.

Other Results

The implementation led to partial outcomes that, even if they weren't initially set as objectives, were a part of the solution and also welcomed as they were progressively achieved. Similarly, some other improvements were reached, despite the fact that they were not what the company was initially looking for, as the aim was to manage projects reliably. In fact, while the usual procedure was to launch projects as they were being sold, launching projects staggered according to the global priorities and the existing capacity not only led to shorter lead times and better use of resources, but to a considerable reduction of the work in process (WIP).

The implications of this fact, achieved in Unit 2, were diverse. Firstly, the management of the system became easier: there were fewer tasks to pay attention to, thereby enabling crystal-clear visibility and simplifying the decision making process. Secondly, the staggering of projects caused the project expenses to be staggered too. As in the new situation projects were launched according to capacity and priorities, the expenses were incurred later, according to the needs and not just as soon as possible. Thirdly, the lead time reduction of projects entailed that the incomes came in sooner, as these incomes are often subject to compliance with certain conditions and/or deliveries. Finally, considering both the staggering of expenses and the acceleration of incomes, it is concluded that the cash flow of the unit was also improved.

3.3 Performance Assessment

The Performance Assessment stage aimed to evaluate the results achieved by the method from the company's perspective and, therefore, focusing especially on Unit 2. To this end, several interviews were conducted individually. In particular, the outcomes of four of these interviews are shown below because they synthetize the findings. Two of them were structured because the information to collect was considered deep and technical—held with the Technical Manager of Unit 2 (TM), responsible for the management of the projects, and the Master Scheduler (MS), responsible for the global planning and information system in both units—, and the other 2 interviews were not structured, as it was searched for a more general view—Business Manager of Unit 2 (BM) and a Technical Developer (TD) from Unit 1—. The key conclusions drawn are the following:

- (TM) The company knows what the situation is at all times. Therefore, the unit is managed according to the general priorities and results are better.
- (MS) CCPM works and priorities are clear. The only reason for the different results between Unit 1 and Unit 2 is the involvement, not the method or the context.
- (BM) The method works. The results have been improved. Now it is known what the situation is. The key is the personal involvement.
- (TD) The rationale behind the method makes sense and is suitable for the context. The underlying idea has probably been forgotten.

4 Conclusions and Future Research

When applying the method to the performing organization, the main issues were two: its applicability and its appropriateness. This research, performed in two similar units of the same company, provides results and conclusions valuable for diverse purposes, as outlined below. It may be helpful guidance for future implementations. It also gives a different perspective of the method, addressing not only its implementation, but its evolution over time too. Finally, some issues that require further research in order to increase the knowledge regarding the real-world use of the method are identified.

4.1 Conclusions

It is important to note that CCPM is a holistic method that aims to manage the projects and resources involved consistent with the particular strategy and the environment considered. The underlying idea is that when the amount of tasks performing simultaneously is smaller and priorities are clear, it is likely that the finished task and completed project rates will be increased. As in the case of Unit 2, the key for this is to focus on certain aspects stated by the method, such as clear and stable priorities, suitable WIP levels and reduction of multitasking, among others. This enabled a global management of the system, resulting in a better global performance. Thus, the general conclusion derived from the results and findings reached in the three-year period after the implementation of the method can be stated as follows: the implementation of the Critical Chain method in the R+D+i context of the company was suitable, sustainable, and provided a competitive edge if compared to the previous situation. This conclusion is based on the results achieved by Unit 2, which gives a clear and direct response to the concerns of the company regarding the applicability and appropriateness of the method.

The implementation process and the results achieved in Unit 2 showed that the method can not only be adapted to the particular features of these contexts, but can also be promptly implemented. In addition, it was demonstrated that it is sustainable from a usability point of view, as a balance between the information given by the information system and the work required to maintain it updated was reached. Moreover, on one hand the information provided by the system was far better than the one formerly available, enabling the organization to react faster and to make more and better decisions. On the other hand, the work required to keep the information system updated wasn't unreasonable. Indeed, Critical Chain advocates for low WIP levels, leading to more economical reporting needs.

In fact, if the situation of both units after their implementation projects is compared, it is concluded that the proper implementation and use of the method entailed a competitive advantage for the company. As for the comparison between the results achieved by both units analyzed if they were competing in the same market, those PM capabilities acquired and developed by Unit 2 would have led the unit to a better competitive position. But it would also be a major mistake if these outcomes were considered as single improvements. These quantitative results were caused by the qualitative improvements attained in Unit 2. Likewise, the main factors under this perspective and several relevant reasons are summarized below.

Visibility:

It is not an advantage itself, but it is a key contributor to success. It shows the current reality and is therefore the foundation for better decision making regarding the quality and timeliness of the decision—i.e. early decisions based on more accurate and updated information. Hence, it is important to understand that it gives an opportunity. For instance, if one company achieves visibility but does not act accordingly, it will not take full advantage of its potential. Furthermore, this will be especially harmful if visibility is only locally observed, for example, from a single project perspective, not considering resource status, priorities among projects, etc.

Flexibility:

The simplicity of the planning and execution management processes given by CCPM are essential for this purpose. It facilitates decisions to be close to the current reality, enabling the connection between the needs and the decisions and/or actions.

Alignment:

The holistic nature of Critical Chain facilitates the consistent alignment of strategies and actions, projects and resources, and planning and execution at all the organizational layers of the system. All these contexts are provided with the information needed to individually perform but connected with the rest of the system. This also implies clear priorities, and prevents problems arising from a lack of view, information or coherency between those parts integrating the system, or mitigates their impact. Thus, the positive impact of the individual improvements is enhanced through a global perspective.

Project Flow:

The increase of the project flow is also a major contributor to the enhancement of the competitive positioning for different reasons: firstly, the time to market for new developments was shortened. Secondly, a substantial reduction of the reaction time was achieved to address tough situations. Thirdly, the increase of the project flow also entailed an increase of the project completion rate. Finally, the combination of flow increase and project staggering caused the cash flow to be improved, impacting positively on the company's economic performance.

In short, all these aspects individually contribute to enhance the competitive position of a company, but the biggest potential comes from the quantitative-qualitative combined contribution. When achieved together and consistently with the strategy and priorities of the company, they can certainly bring it to a better competitive position.

The last conclusion of the research refers to the key success factors for the implementation of CCPM. The pilot test was performed in Unit 1, achieving tangible results that showed the potential and applicability of the method in that context. Nevertheless, the changes needed inside the unit to successfully expand the method were not materialized. While Unit 2 was driven aligned with global priorities, Unit 1 lacked visibility and priorities, causing a misalignment between projects, resources and goals. The main reason for that was a lack of engagement and even resistance to change from some people. In particular, the attitude of certain managers, that initially agreed to perform in accordance with the method, was very harmful for the implementation: not having assumed their responsibilities regarding the method, their staff was not forced to comply with the requirements of the method. Thus, the method never worked properly in this unit.

It is concluded that there are two essential components necessary in an implementation: the adaptation of the method to the context, and the acceptance of the method inside the organization. The adaptation rests on the comprehension of the context and the method, so that a suitable model is created. The acceptance, instead, is related to other factors such as the culture and maturity of the company, its willingness to change and the commitment towards rigor as required by the method. Therefore, it is also concluded that the engagement of all the parties involved is an absolute prerequisite for a successful implementation.

Finally, it must be asserted that there is no reason to conclude that the particular features of this R+D+i context may recommend not to implement CCPM. In fact, it is not a method designed for a specific industry, and aspects addressed by the method such as lead time reduction, higher productivity or better cash flow are of general interest for companies. Therefore, this approach seems to be particularly interesting for those contexts where multiple projects are performing simultaneously and share resources, due to the difficulty of managing them.

4.2 Future Research

The results achieved by both units and the different behaviors arisen in such similar contexts confirmed that the human factor is a key success component when implementing CCPM. It is clear that the involvement of the senior management is essential, but even this may be not enough. Thus, further research is needed so as to identify those fundamental aspects that can cause such an implementation to fail, even if a success case is being achieved in another unit of the same company at the same time, and to find appropriate ways of addressing them.

Another issue that, even if it was not a real problem in the period observed, might have been a drawback was the management of resources shared by Unit 1 and Unit 2. Because of the low saturation of these resources, both units were considered to be independent. However, in a different scenario where saturations where higher this could be a major problem: as units were arranged and managed as independent systems, they would not be capable of managing these resources properly, resulting in an internal misalignment of both units and in worse results. Similar situations where parts of a company are managed independently but share certain resources are not unusual. Therefore, it would be worth to develop further research about this issue in order to identify appropriate approaches to deal with such situations.

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A Project Monitoring and Control System Using EVM and Monte Carlo Simulation

Fernando Acebes, Javier Pajares, José Manuel Galán and Adolfo López-Paredes

Abstract Earned Value Management (EVM) tells the project manager whether the project has overruns (costs, delays) or it is running better than planned. But taking into account uncertainty, the methodology does not specify whether the deviation from planned values is within the possible deviations derived from the expected variability of the project. In this paper, a different approach is proposed for monitoring and control projects under uncertainty. The Monte Carlo simulation is used to obtain the "universe" of possible project runs and new and innovative graphs are defined. When the project is running, its current situation can be represented with these graphs, so that it can be established whether the cost or duration of a project is under control at a given time for a given level of confidence.

Keywords Earned value management · Project control · Uncertainty management · Monte Carlo simulation

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1 Introduction

Project control consists on the process of monitoring, analysing and reporting the progress of a project in order to achieve the performance objectives and goals defined during the planning stage (Project Management Institute 2013).

This task, developed alongside the complete life cycle of the project, allows project managers to revise the adopted measures and to establish predictions about duration, scope and costs.

The process tries to identify as soon as possible those areas of the project that require especial attention and consequently establish the appropriate corrective or preventive actions to sort out the problems.

An effective control system has to clearly define monitoring strategies (when and how) and intervention strategies (when and how). The most decisive variables to specify those strategies are the timing and the quantity of project control activities (Hazir and Schmidt 2013).

Earned Value Management has been traditionally used as a control project methodology to monitor time and costs. This technique is designed under the assumption of a deterministic environment with complete information about the tasks of the project. However, during project development, uncertainty and variability are very common in most of the project tasks in real contexts (Pajares and López-Paredes 2011).

Cost and time uncertainty may appear during several stages of the project life cycle. It can have different sources such as technology, productivity, human resources, economic conditions or other risks or events and as consequence of several aspects for example, the development of projects without enough previous experience, the intrinsic variability of the cost, time and quality measures, ambiguity of the project, lack of concrete objectives, data, etc. (Ward and Chapman 2003; Jaafary 2006; Khodakarami and Abdi 2014).

The ubiquitous presence of uncertainty in project management is activating research that takes into account task uncertainty in project control and monitoring (Hazir and Shtub 2011; Pajares and López-Paredes 2011; Vanhoucke 2012; Aliverdi et al. 2013; Acebes et al. 2013, 2014).

This paper is aimed at controlling and monitoring an illustrative project using EVM methodology and comparing it with two recent techniques that incorporate uncertainty in tasks. In order to do so, some of the control charts offered by each methodology are presented, and a comparison and analysis of the usefulness of each option for an efficient project control is made. The compared approaches in regards to the EVM are the proposals by Pajares and López-Paredes (2011) and the proposal by Acebes et al. (2014).

The rest of the paper is structured as follows: in the next section the different control methodologies are explained; subsequently, the project used as example and the planned and real states used with the simulation are described in detail. Graphical results are then provided to compare methodologies. Finally, conclusions are presented in Sect. 4.

2 Monitoring and Control Project Management

2.1 Earned Value Management

EVM is a control and monitoring project management methodology that uses monetary units as common basis to quantify the progress of the project. This technique integrates schedule and cost control in the same graphical representation.

It is based on the representation of three measures: the Budgeted Cost for Work Scheduled (BCWS) also called Planned Value (PV); the Actual Cost for Work Performed (ACWP) also called Actual Cost (AC); and finally, the Budgeted Cost for Work Performed (BCWP) or Earned Value (EV). EVM is very popular and there is a wide range of scientific literature that address details about the description and use of the methodology (see for instance Anbari 2003; Fleming and Koppelman 1998; Project Management Institute 2005; Cioffi 2005).

A refinement to the methodology was introduced by Lipke (2003, 2004) including the concept of Earned Schedule (ES). ES corresponds to the date in which the current EV should had been obtained. This concept solves the problem that appears near the end of the project, when EV gets close to the PV curve and can mislead control indexes.

However this is not the only problem of the EVM methodology (Kutsch and Hall 2005): critical and non-critical activities are not distinguished, tasks are assumed independent, management and the behaviour of the project team are not taken into account, not even the topology of the network. Besides, traditional EVM does not include risk or uncertainty task management.

2.2 Schedule Control Index (SCoI)/Cost Control Index (CCoI)

Pajares and López-Paredes (2011) developed a methodology integrating risk management and EVM. The gist of the approach is not only to figure out if the project is delayed or not (or if it over budgeted) but also if this situation is within the expected range of variability of the project.

Authors use Monte Carlo simulation to estimate the statistical parameters of the probability distributions at the conclusion of the project. Once they are obtained, the project manager decides a confidence level to control and monitor the project in schedule and cost. When the project is controlled in an intermediate stage, authors propose to split the buffer or confidence margin at the end of the project among all time intervals.

In order to do that, the Project Risk Baseline is defined as the evolution of the value of project risk during the project life cycle. The weight of the final buffer in each period is distributed according to the expected risk reduction in every consecutive interval.

Finally, the approach is completed integrating the indexes and ratios obtained from the EVM together with the weighted buffer in each time interval. This integration leads to two new control indexes SCoI (schedule) and CCoI (cost). Acebes et al. (2013) complete the previous work providing a graphical control framework that incorporates SCol and CCol indexes. The progress of the project can be intuitively and visually understood depending on the value of the indexes in the graphical framework. In each time period the project can be found in one of the following states: the project is being executed according to the planned baseline (in time and/or cost), the project is ahead (or under budget) within the range of expected variability, the project is ahead (or under budget) without the expected variability, the project is delayed (or with over cost) within the range of planned variability or, in the last case, the project may be delayed (or with over cost) without the range of planned variability consequence of the tasks.

2.3 Triad (%, Time, Cost)

Acebes et al. (2014) use Monte Carlo simulation to determine multiple instances according to the stochastic planned project and obtain in this way the probability functions of time and cost for every percentage of the project (measured in terms of cost). The real development of the project can be compared with the different percentiles obtained from the model of the project, according to the expected variability, in such a way that the project manager can figure out the range of variability of the execution, and decide if the margin is adequate (within the planned variability) or if the situation is a warning that alerts about the need to apply corrective measures to the project.

This methodology is also complemented with two additional charts to control project cost and schedule. They are built comparing each one of the percentile curves with the planned value (PV) curve, and representing the difference in function of the percentage of execution (expressed in cost of the project). This representation uses PV as x-axis highlighting the differences of the rest of the curves. When the advancement of the project is also represented, the under or over runs can be calculated considering the PV or any other percentile curve. Corrective actions can be introduced if the project is out of the confidence margin considered by the project manager.

3 Monitoring and Control Project Management

In order to compare the different monitoring and control project methodologies and to illustrate the different control charts, we have chosen the project model represented in Fig. 1 using an Activity on Node (AON) network. This graph has been used by Lambrechts et al. (2008) in a previous research.

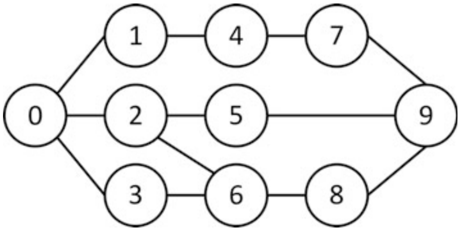

Fig. 1 Activity on node network diagram of the simulated project

The network used is simple but includes enough complexity to illustrate the methodologies. It includes three parallel paths, two of them connected through an activity.

Task durations have been modelled by means of normal distributions according to the parameters shown in Table 1. It is important to underline that this is not a restriction to the methodologies as any other distribution can be included. In the same way, activities are considered independent but any correlation among the tasks can be included in the definition of the project.

Table 1 includes the planned tasks, each one with its expected duration and its associated expected cost. We have also included in the same table a hypothetical case of executed project, specifying the real duration of each activity. Actual cost is directly obtained once the task duration is known.

Figure 2 represents the Gantt diagram of the planned value and the actual cost. Those activities longer than expected are highlighted.

3.1 Earned Value Management (EVM)

Figure 3a represents the EVM methodology using the data (planned and executed) of the project described earlier; Fig. 3b is the chart representing the cost and schedule variance and Fig. 3c shows the Earned Schedule.

Table 1 Duration of project activities of the case study. Durations are modelled as normal distributions; μ represents the mean duration and σ^2 the variance. Cost depends on duration

Activity	Planned			Actual execution	
	μ	σ^2	Total cost	Duration	Total cost
A1	2	0.15	1510	2	1510
A2	4	0.83	7000	4	7000
A3	7	1.35	651	7	651
A4	3	0.56	2748	4	3628
A5	6	1.72	204	6	204
A6	4	0.28	5000	5	6210
A7	8	2.82	7000	8	7000
A8	2	0.14	500	3	600

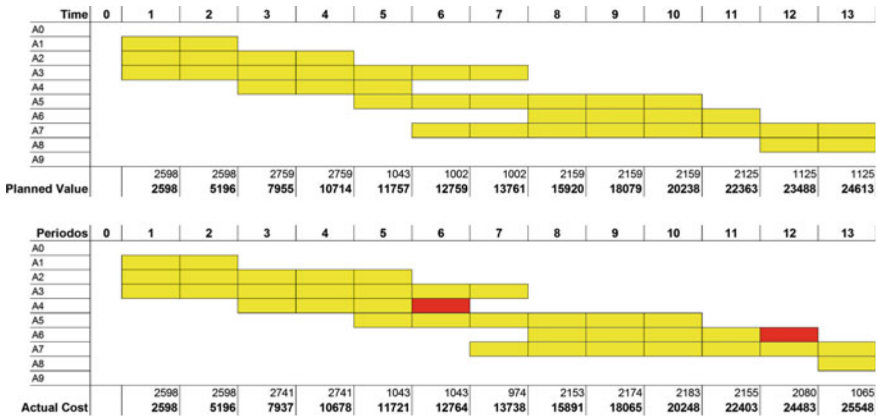

Fig. 2 Gantt diagram of the planned and executed projects

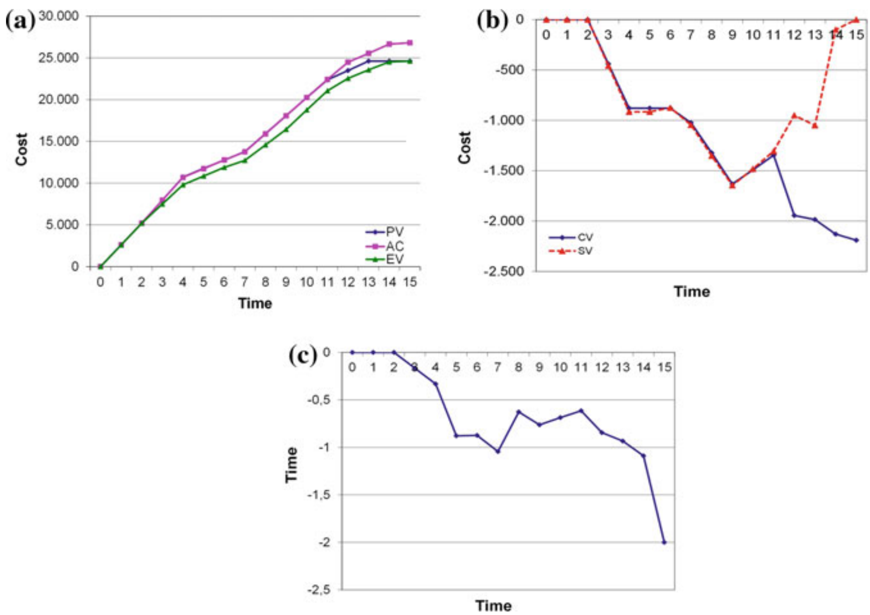

Fig. 3 **a** Represents the traditional EVM chart with PV, AC and EV; **b** represents the schedule and cost variance of the executed project; **c** represents SV(t)

Figure 3b illustrates that the schedule variance of the project (SV) gets close to 0 in the final stages of the project. Earned Schedule solves this problem. Figure 3c represents the earned schedule variance SV(t); the project finishes delayed two time periods compared with the planned value.

In spite of obtaining the evolution of the delay of the project in each time period, EVM does not incorporate uncertainty and hence, it is difficult to assess whether this delay is within the expected range. Traditional EVM does not provide a confidence margin or a control buffer at the moment of monitoring the project.

3.2 Schedule Control Index (SCoI)/Cost Control Index (CCoI)

This methodology takes into account the uncertainty of activities. We have chosen 90 and 10 % percentiles as confidence margin to illustrate the case study, both, in cost and schedule. Cost Control Index, CCoI, and Schedule Control Index, SCoI are represented in Fig. 4. In both figures, indexes—CCoI and SCoI—are situated between the x-axis and ACBf and ASBf, respectively. This means that the project is running over cost and is delayed, but is within the 90 % margin that the project manager considered as acceptable.

In this case study the confidence margin or control buffer has been established between 10 and 90 %. If the project manager decides to be stricter and to control the project more rigorously, a tighter range can be selected (25 and 75 %, for instance). In such situation, calculations and control charts should be recalculated again, obtaining new control (ACBf and ASBf) curves and new indexes (CCoI and SCoI).

This methodology gives the option to control a project considering uncertainty. Nonetheless, it is important to notice that this approach complements and should be used together with EVM. This framework provides the basis to calculate the indexes and to analyze the possible overruns of the project. The SCoI/CCoI indexes do not provide this information by themselves and CV and SV(t) are required to obtain them.

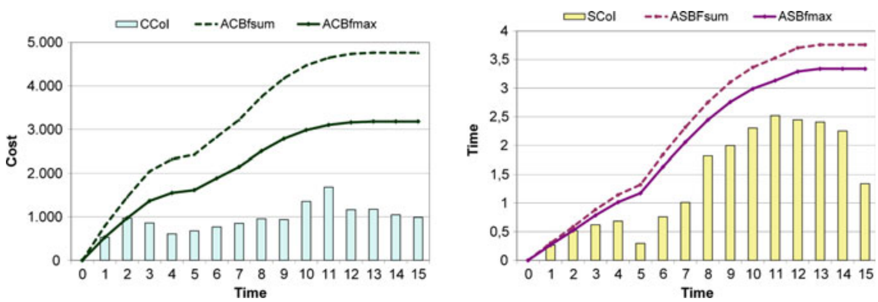

Fig. 4 Cost Control Index *CCol*, and Schedule Control Index *SCol*

3.3 Triad (%, Time, Cost)

This methodology also takes into account task uncertainty. The technique uses the Monte Carlo simulation to obtain the cost and schedule for every percentage of advancement of many possible instances of the project according to its probabilistic definition. Figure 5 represents the triad (%, t, c) from data obtained through simulation. The different charts are obtained during the planning stage and later, during the execution of the project; the curve representing the real development of the project is included to monitor and control it.

Figure 6a shows the graphic (%, cost). For each percentage the corresponding cost is projected: during the planning stage the percentile and PV costs, and during the execution cost the actual cost. Linearity is the consequence of the assumed proportionality between task duration and task cost.

Similarly, Fig. 6b represents the evolution of the schedule. In this case the shown chart (t, %) is obtained projecting for each percentage of project execution its corresponding time.

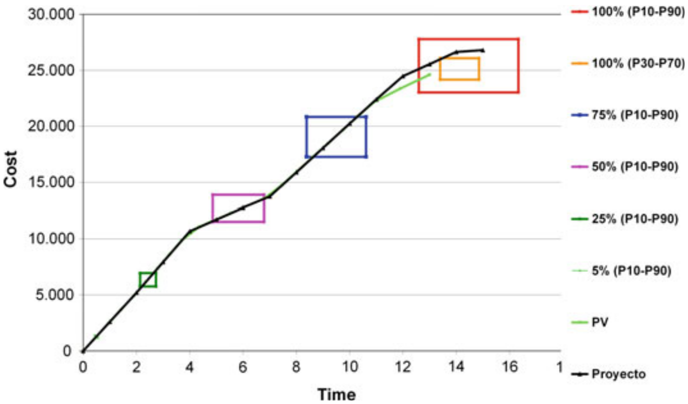

Fig. 5 Triad (%, t, c)

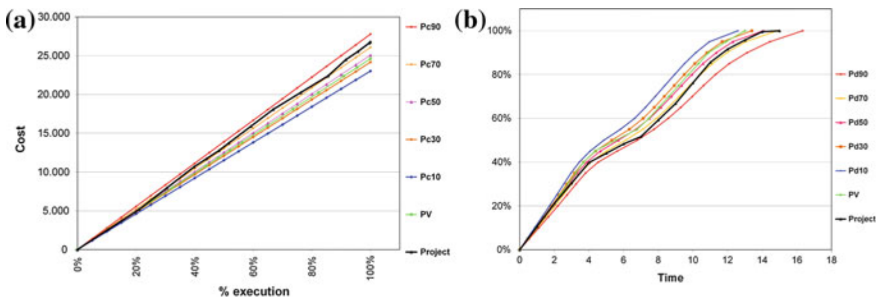

Fig. 6 Triad projections. **a** represents (%, cost) and **b** shows (time, %)

This methodology provides the percentage curves of the project according to the probabilistic definition of the tasks. When the actual execution is represented, the percentile in which the project is at a given moment can be observed as well as its cost and timeframe. Since all the percentiles are represented, the project manager knows if the project is within the prefixed percentile range and consequently is able to adopt corrective measures if necessary. Moreover, the project manager can choose to use different ranges for different moments of the project depending on exogenous factors. Besides, time and cost graphics represent absolute units, so the information about the magnitude of overruns is also available. Differences between the planned value curve (PV) with respect to the rest of the percentile curves (TSV) can also be calculated simplifying the interpretation.

4 Conclusions

In this work we have compared several methodologies—EVM, Control Indexes, and Triads—to monitor and control projects using the same stochastic project definition and a real project execution.

Given the sophisticated capabilities to integrate uncertainty in the control stage, we can conclude that the triad methodology proposed by Acebes et al. (2014) is more complete and powerful than the alternatives. It incorporates risk analysis in the project, introduced by means of uncertainty in task durations. This feature allows the project manager considering different confidence margins along the project before adopting corrective actions. Besides, the project manager can also obtain measures of the magnitude of deviations depending on the baseline. This methodology extends EVM but the required effort to implement and interpret it is low.

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Proposal for a Maturity Model Based on Expert Judgment for Spanish Project Organisations

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Abstract Maturity models indicate a path for achieving excellence in project management by evaluating how organisations implement best practices. The Software Engineering Institute developed in 1987 the first maturity model designed to help software companies improve their processes—the *Capability Maturity Model*. Various models have since been proposed, and they are most commonly employed in areas where project management techniques are frequently used (US, UK, and Latin America). The excessive variety of maturity models has made their practical application in business difficult. In Spain, there is little documentation available on the current use of maturity models in organisations and this study aims to fill that gap. To achieve this it was necessary to consult project management experts to establish the most common business practices and so propose the basis of a maturity model for Spanish project organisations.

Keywords Models · Organisations · Project · Practices

1 Introduction

The level of skills demanded in the global market has grown rapidly in recent years. The unstable global economic situation has meant that companies and employees are constantly encouraged to revise their actions to ensure survival. It is even more essential that projects adhere to the estimated cost and completion deadline. Performance must be excellent because competition is fierce. Maturity models in project management have arisen in this scenario as a response to the need for organisations to self-assess and compare themselves with other companies in their field in order to achieve excellence and ensure survival.

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Project management remains an abstract concept in Spain; however, in the last decade it has been imposed on project-based companies because of the need to deliver on time to survive. Maturity models have been developed in countries where project management is common and more than 30 models are currently available. This diversity makes it difficult for organisations to choose correctly—and money and time has been often wasted as a consequence of inappropriate choices.

Studies by Kerzner (2001), Sukhoo (2009), Kwaak (2002) and Kwak and Ibbs (2002) show a direct relationship between the correct application of maturity models in project management and the success of projects undertaken by an organisation.

A maturity model compares practices and processes with requirements and performance in order to identify possible areas for improvement in organisations.

This study is justified by the need to clarify the vision of maturity and its application in Spanish organisations, as well as the need to develop a model that meets the requirements of Spanish projects.

Two studies were carried out to this end: firstly, a comparison of existing maturity models was made; and, secondly, a field survey of Spanish companies was made to gain an understanding of how companies view maturity models and project management standards.

2 Historical Evolution of Maturity Models

Authors such as Lukosevicius (2005) place the foundations of maturity models in Crosby's 1979 model. Crosby structured a model known as the *Quality Management Maturity Grid* (**QMMG**) that was based on five incremental levels of maturity linked to the adoption of quality concepts in an organisation.

Deming introduced in 1986 various practices for the continuous improvement of quality management processes in an organisation: including the Deming cycle (PDCA). This cycle consists of four repeated stages: *plan, do, check, and act.*

From the model of Crosby and the ideas of Deming, the Software Engineering Institute (SEI) at Carnegie Mellon University and the United States Defense Department developed a model to evaluate and encourage the management of software processes known as the *Capability Maturity Model* (**CMM**).

CMM development began in 1987 and an initial version was launched in 1991. It focuses on improving processes in software engineering projects and offers five levels of maturity for evaluations in 18 process areas, 52 objectives, and over 300 key practices. The success of CMM in the software industry inspired experts in the field of project management to develop a maturity model for project management organisations. As a result, numerous and valuable maturity models in project management have been developed.

The *capability maturity model integration* (**CMMI**) appeared in 2000 as a successor to the more generally applicable CMM. CMMI integrates areas such as software engineering, product development, and services to improve process efficiency. In 2001 Harold Kerzner (University Baldwin Wallace, and a former professor at the University of Illinois) introduced a maturity model known as **K-PMMM**. The model has five levels and was applied through a questionnaire-interview that divided the results into various scores and considered the maturity model from the point of view of strategic planning. In the same year, Project Management Solution Software in the United States developed the **PMS-PMMM**, a maturity model that integrates the five levels proposed by the SEI with nine knowledge areas of the Project Management Institute (PMI). The model is readily operational and understandable and therefore was easily accepted. The *project portfolio management maturity model* (**PMS-PPMMM**) was launched soon afterwards and added a portfolio dimension to the previous model. Motivated by the evolution of project management in Europe and America, the Advanced Engineering Association (ENAA) of Japan launched in 2001 the *project and program management for enterprise innovation* **(P2M)**, a maturity model based on Kaikaku project management (KPM). The model aimed to encourage the concept of intellectual property of managers and workers in preference to technology skills in project management. University of Berkeley professors Ibbs and Kwak proposed the *project management process maturity model* (**PM2**) in 2002 as a more comprehensive maturity model to determine and compare levels of project management in organisations. In 2003 the PMI launched the *organisational project management maturity model* (**OPM3)** which aimed to help organisations translate strategy into successful performance. In 2004 the Office of Government Commerce (OGC) launched a maturity model for the project dimension (P1M3). This later evolved into the *Prince2 Maturity Model* (**P2MM**) which was specifically for organisations that use the PRINCE2 method. In the same year, the project management team from the Vienna University of Economics and Business Administration developed the Cobweb Model, a six-level model aimed for self-assessment and benchmarking organisations. Finally, in 2006 the OGC launched a complete version of P3M3 which included portfolio, program, and project dimensions for any organisation working with projects (Renée ter Haar 2008).

The following figure shows the connections between the models (Fig. 1).

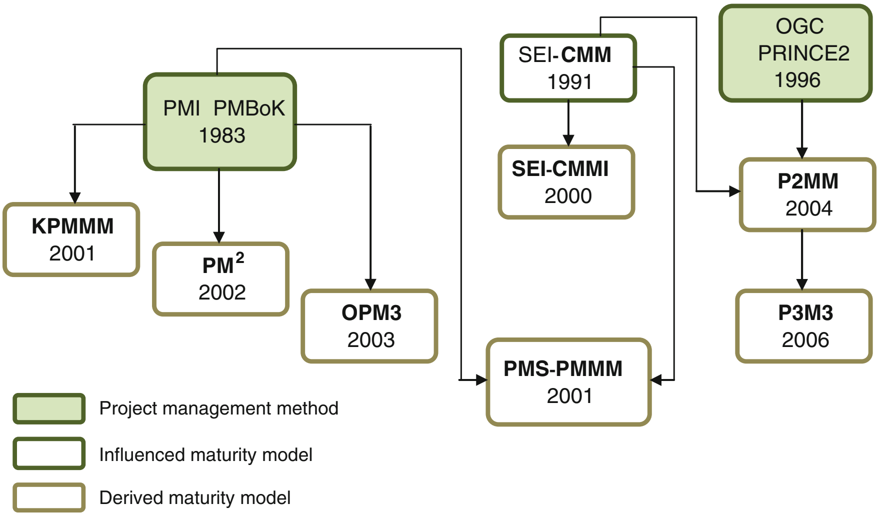


Fig. 1 Chronological relationship of the maturity models (adapted from ter Haar 2008)

3 Research Objectives and Proposed Hypotheses

3.1 Main Objective

The main objective of this article is to establish a basis for developing a maturity model that remedies the shortcomings of existing models. These shortcomings have been identified in a survey of experts (Study 1). Another study examines the current literature (Study 2). The aim is to make it easier for organisations to understand the various models and propose a new approach for future research in light of current deficiencies.

3.2 Hypotheses Proposed

Seven hypotheses were proposed for Studies 1 and 2:

H_1 By an analysis of existing maturity models it is possible to identify deficiencies and develop proposals for improvement

H_2 By an analysis of the current use of maturity models in Spanish organisations it is possible to identify deficiencies and develop proposals for improvement

H_3 The application of standards in project management implies a higher level of maturity in project management

H_4 The perception of good performance in time-performance-cost is proportional to the perceived level of performance in risk management

H_5 Good performance on critical aspects of success (time-performance-cost and risk management) is related to the level of maturity of the organisation

H_6 Organisations are unaware of the need to make self-assessment and this leads to a low level of maturity in Spanish companies

H_7 Use of formal methodology (maturity models) for the self-assessment of an organisation implies a higher level of maturity in project management performance

4 Studies Made

To test the hypotheses, we conducted two studies:

4.1 STUDY 1: Comparison of Maturity Models

The objective of this study was to identify the main characteristics, strengths, and weaknesses of the existing maturity models—thereby offering a clear view that will help users choose, as well as facilitating the development of new approaches.

The models selected were chosen from those identified in the literature—based on the following criteria:

(1) Applications and references in the literature indexed under project management.
(2) Emphasis given to models in the analysed articles.
(3) Adequate theoretical and practical foundations.
(4) Expert judgment offered about the implementation of these models.

Accordingly, the following maturity models were selected:

CMM−CMMI KPMMM PM2 OPM3 P2MM P3M3

By studying each maturity model independently, judgments were made regarding their strengths and weaknesses according to the evidence reviewed and results of the applications.

4.1.1 Results of Study 1: Testing the Hypothesis

A large comparative table (Table 1) with the following information was produced as a result of the study:

- **Year**: date in which the maturity model was released;
- **Author**: organisation or person who originally developed the model;
- **Main feature**: summary of its most characteristic feature;
- **Comparable features**: significant features for which information has been obtainable for each model;
- **Strengths**: according to the authors reviewed;
- **Weaknesses**: according to the authors reviewed;
- **Levels**: a simple parallel overview of the levels of each maturity model. We can consider, for example, at Level 1 'Ad hoc' (PM^2) that a company is in an 'Initial' state of evolution since its processes are carried out exclusively for each project (CMM and CMMI).

The comparison chart reveals the most common weaknesses among the models. This will aid the development of a model that responds to these deficiencies and so answers Hypothesis 1.

By observing the weaknesses of each model, we can identify the most repeated weaknesses:

- Ignoring political, social, economic, and cultural aspects;
- No measurement for staff skills;
- Excessive bureaucracy;
- Processes are too long and rigid;
- Use of jargon.

4.2 STUDY 2: Comparison of Maturity Models

To develop a model that responds to the current situation of Spanish project organisations, we must first understand their level of knowledge about international standards in project management, and the project management activities that have been carried out by these organisations.

To perform this study, we chose to use expert judgments gathered through a survey of industry professionals. The participants were mostly professionals and experts in project management working in Spanish organisations. An on-line survey was also developed and sent to other organisations (many of which responded with interest).

We analysed 43 survey returns from professionals in 27 organisations in various sectors.

The questionnaire consists of 11 questions (see Fig. 2) divided into two categories: six questions of a personal nature to help position the respondent and

Table 1 Comparative study of maturity levels

	CMM (Capability maturity model)	CMMI (Capability maturity model integration)	K-PMMM (Kerzner project management maturity model)	PM^2 (Project management process maturity model)	OPM3 (Organizational project management maturity model)	P2MM (Prince2 maturity model)	P3M3 (Portfolio, programme and project management maturity model)
Year	1991	2000	2001	2002	2003	2004	2006
Author	SEI	SEI	Kerzner	Kwak & Ibbs	PMI	OGC	OGC
Main characteristic	First maturity model developed to evaluate the software capabilities in 5 levels	Model evolution of CMM with aim of unifying systems. Generic with 6 ability levels and 5 maturity levels according to two types of representations.	Allows overlaps and feedback between maturity levels. Levels 3, 4, and 5 form repetitive cycle leading to excellence. Defines maturity from strategic planning	Based on methodological structure of PMI. Divided into 9 knowledge areas and 5 project management processes	Most widely distributed model. First to use idea of dimensions instead of maturity levels. Handles portfolio, program, and project dimensions	Model is specifically for measuring the maturity level of project organisations that use PRINCE2	Model of PRINCE2 applicable to any project organisation. Handles portfolio, program, and project dimensions
Comparable features	• Original model • Specific model (software industry) • Only handles project dimension • Generally applicable for any project organisation • Not often currently used • Cannot be certified	• Based on CMM • Generic model • Only handles project dimension • Generally applicable for any type of organisation • More widely used than CMMI but little used currently • Certifiable by the CMMI Institute (part of SEI)	• Based on PMBok • Generic model • Handles only the project dimension • Generally applicable to any project organisation • Often used for studies, but little used by companies • International Institute for Learning offers online evaluation through the KPMMM	• Combination of CMM and the principles of PMI • Generic Model • Handles only the project dimension • Generally applicable to any project organisation • More exhaustive than CMMI for benchmarking, but little used in businesses • Cannot be certified	• Directly derived from PMI principles • Generic model • Handles project, program, and portfolio dimensions • Generally applicable to any project organisation • Model most commonly used—alongside P3M3 • Certifiable by PMI	• Derived from CMM, and adapted to PRINCE2 processes. Evolution of P1M3. • Generic model • Only handles project dimension • Only applicable in organisations that use PRINCE2 • Only used by companies that use PRINCE2 • Certifiable by PRINCE	• Created from P2MM, derived from CMM, adapted to PRINCE2 processes • Generic model • Handle project, program, and portfolio dimensions • Generally applicable to any project organisation • Most commonly used model—alongside OPM3 • Certifiable by PRINCE

(continued)

Table 1 (continued)

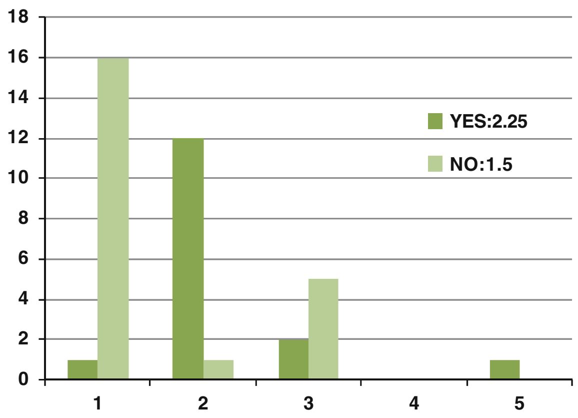
	CMM (Capability maturity model)	CMMI (Capability maturity model integration)	K-PMMM (Kerzner project management maturity model)	PM^2 (Project management process maturity model)	OPM3 (Organizational project management maturity model)	P2MM (Prince2 maturity model)	P3M3 (Portfolio, programme and project management maturity model)
Strengths	• Useful for software companies • Defines areas where improvements can be made • Best known model	• Offers a set of best practices based on successful cases • Offers a method for integrating functional elements in an organisation	• Model focused on organisational strategic planning • Simple tool that is easily applied (consisting of 183 questions) • Easy access by internet • Allows overlap and feedback between levels of maturity. • Levels 3, 4, and 5 form repetitive cycle leading to excellence • Measures staff skills	• Based on PMBok, developed by the PMI, which inspires confidence • Easy to understand and apply • For benchmarking it provides relative level of maturity in comparison with other organisations • Enables companies to make comparisons in the same industry or sector • Handles functional organisations	• Based on PMBok, developed by the PMI, which inspires confidence • Offers knowledge about what constitutes best practices in project management • Integrates organisational strategy with individual projects • Takes into account correlations between existing processes • Proposes repetitive cycle of improvement • Always maintains global vision of the business	• Developed by PRINCE—which inspires confidence • Easy internet access • Process maturity level. Organisational objectives are emphasised	• Developed by PRINCE—which inspires confidence • Easy internet access • Process maturity level. Organisational objectives are emphasised
Weaknesses	• Does not consider political, social, economic or cultural aspects • Does not measure staff skills	• Does not consider political, social, economic, or cultural aspects • Does not measure staff skills	• Does not consider political, social, economic or cultural aspects • Model restricted to a single corporate culture	• Does not consider political, social, economic or cultural aspects • Does not take social abilities into account	• Does not consider political, social, economic or cultural aspects • Difficult to understand as very	• Does not consider political, social, economic or cultural aspects • Does not take social abilities into account	• Does not consider political, social, economic or cultural aspects • Does not take social abilities into account

(continued)

Table 1 (continued)

		CMM (Capability maturity model)	CMMI (Capability maturity model integration)	K-PMMM (Kerzner project management maturity model)	PM^2 (Project management process maturity model)	OPM3 (Organizational project management maturity model)	P2MM (Prince2 maturity model)	P3M3 (Portfolio, programme and project management maturity model)
		• Works almost exclusively in development processes and software maintenance • Requires staff with considerable experience • Excessively bureaucratic • Procedures are rigid • Procedures are rigid	• Almost exclusively works with organisational processes • Requires staff with much experience or excessively expensive training • Excessively bureaucratic • Processes are too long • Processes are too long	• Does not take into account needs in developing nations • Does not measure staff skills		different to other models • Identifies the percentage of organisational maturity rather than maturity level	• Does not cover personnel and contract management • Only applicable to organisations that use the PRINCE2 method	• Does not cover personnel and contract management
Levels	*1*	Initial	Initial	Common language	AD hoc	–	Awareness of progress	Awareness of progress
	2	Repeatable	Managed	Common processes	Planned	Standardisation	Repetable process	Repeatable process
	3	Defined	Defined	Single methodology	Managed at project level	Measurement	Defined process	Defined process
	4	Managed	Quantitatively managed	Benchmarking	Managed at corporation level	Control	–	Managed process
	5	Optimised	Optimised	Continuous improvement	Continuous learning	Continuous improvement	–	Optimised process

Fig. 2 Survey in Study 2



professional organisation in the framework of project management; and 5 questions regarding the organisational use made of project management standards and maturity models.

The questions in the survey are oriented towards major world renowned standards of project management and maturity models. Respondents are always given an option to state that they use a system that is not indicated, or that there are insufficient criteria to answer satisfactorily—thereby avoiding forced and unrealistic answers.

4.2.1 Results of Study 2: Hypothesis Testing

A comprehensive analysis of the responses to the surveys was performed. These responses enabled the remaining research hypotheses to be tested.

From the analysis it can be concluded that Spanish organisations are generally unaware of the value of maturity models for system performance assessment. This lack of awareness means that these models are not applied and so deficiencies in their use cannot be identified—which answers *Hypothesis 2*.

Hypothesis 3 is tested by analysing at what level the respondents believe their organisation is positioned (Question 5) depending on whether or not any project management standard is applied (Question 1).This data is reflected in Fig. 3.

It is noted that most organisations do not employ standards and are therefore positioned at Level 1; while most organisations that do employ standards are positioned in Level 2. Levels 4 and 5 are excluded from the analysis as there are no samples at this level, and those who responded that their organisation was at Level 3 also generally reported that project management standards were applied. Therefore, the hypothesis is confirmed.

Accordingly, we can say that: *organisations applying project management standards have a higher level of maturity.*

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

INTERNATIONAL STUDY ON AWARENESS OF MATURITY LEVELS IN PROJECT MANAGEMENT

The aim of this survey is to study awareness of international standards and practices relative to maturity levels. We are grateful for your cooperation and will send you a copy of the results of the study. Please answer all of the questions regarding your experience.

Your e-mail: ______________________

Mark with an 'X' the sector to wich your organisation belongs:

__Academic ___Manufacturing __Energy __ Other

Indicate your age group with an 'X':

30 or below ☐ 31 - 40 ☐
41 - 50 ☐ Older than 51 ☐

Indicate with an 'X' the number of years of experience you have working on projects:

3 or less ☐ 3 - 10 ☐
11 - 20 ☐ More than 20 ☐

How many projects does your organisation handle per year:

3 or less ☐
4 - 10 ☐
More tan 11 ☐

Indicate the level of education you have completed:

High School ☐ Technician ☐
University degree level ☐ Postgraduate ☐
Other (please specify) ☐ ______________________

Indicate with an 'X' any certificate you may have been awarded

PMP® ☐ IPMA® ☐ Prince2 ☐
Other (please specify) ☐ ______________________

1. **Which of the following standards are applied in your organisation?**

   __IPMA __PMI __PRINCE2 __KPM (P2M) __Other

   __To answer the question I need more information about standards

2. **Give a score of your organisation performance in the developed projects regarding the success criteria** (use an X to indicate your score on a scale of 1-10 with 10 being the highest score).

Time	1	2	3	4	5	6	7	8	9	10
Cost	1	2	3	4	5	6	7	8	9	10
Results	1	2	3	4	5	6	7	8	9	10
Risk Management	1	2	3	4	5	6	7	8	9	10

3. **Has your organisation made an analysis of its level of preparation regarding the project management? (maturity level)** __Yes __No

4. **Does your organisation have a documented methodology or model for managing projects?**
   __Yes __No

5. **In the light of your experience, mark an X alongside the statement that most closely describes your organisation regarding the project management :**
   __ There is no investment in project management training, no acknowledgement is made of the benefits of project management, and there is little management interest in the subject.
   __ The benefits of project management are recognised and there is organisational support at all levels, moreover, there is awareness of the need for processes, methodologies, and cost control. There is a training program.
   __ There is management and cultural support at all levels. Projects are managed in an informal manner. There is qualitative and quantitative recognition of the ROI for project management training. The improvements brought about by project management are recognised.
   __ There is a project office that emphasises process improvement. Benchmarking is undertaken with similar and distinct industries. The benchmarking is quantitative in processes and methodologies, and qualitative in the application of project management.
   __ There is a register of lessons learnt, as well as a mentoring program run through the project office, plus a strategic plan for project management.

Fig. 3 Use of standards/maturity level

To test *Hypothesis 4*, the responses to Question 2 in terms of the performance of the organisation in cost-time-performance and risk management were analysed—and the correlation between them can be seen. The results are shown in Fig. 4 where

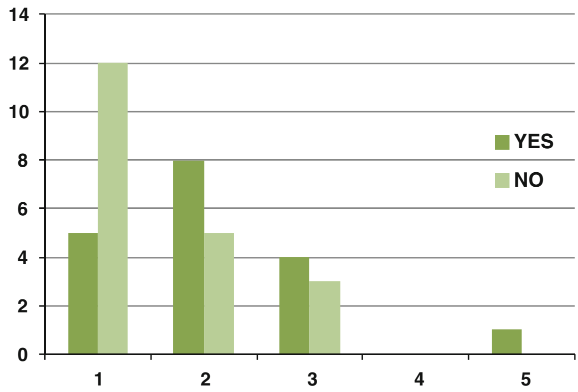


Fig. 4 Cost-time-performance/risk management

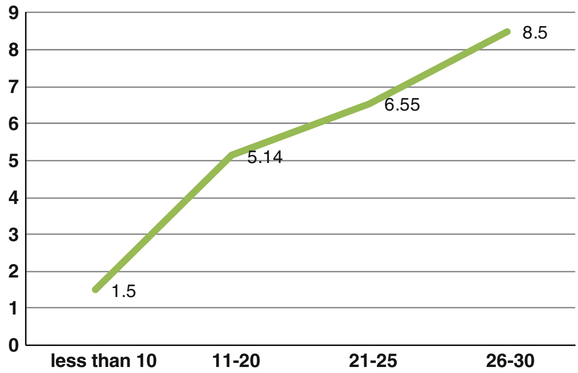


Fig. 5 Cost-time-performance and risk management/maturity levels

it is clear that a higher evaluation for the elements of cost-time-performance produces a greater evaluation for risk management.

Therefore, we can affirm that: *the greater the evaluation of cost-time-performance, the greater the evaluation of risk management for the organisation.*

Hypothesis 5 is confirmed by comparing the evaluations of cost-time-performance and risk management regarding the maturity levels of the organisation.

In Fig. 5 we can see that: *the greater the consideration of values in terms of cost-time-performance and risk management, the greater the level of maturity of the organisation perceived by the respondents.*

To test *Hypothesis 6* the answers to Question 3 ('Has your organisation made an analysis of its level of preparation with respect to project management?') are

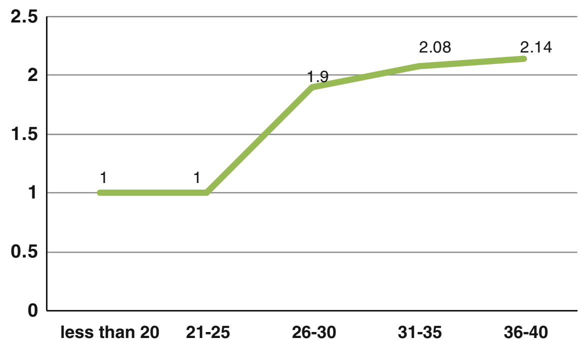


Fig. 6 Evaluation/level of maturity

compared to Question 5 to see whether or not the level of maturity is affected by the use of generic assessment methods.

The result can be seen in Fig. 6 we observe that organisations at Level 1 have not generally performed an analysis of their level of preparation with respect to project management. However, most of those organisations found in Level 2 have made such analyses.

We can therefore say that: *organisations that do not carry out self-assessments have a lower maturity level than organisations that have a system of performance evaluation.*

Finally, *Hypothesis 7* is confirmed by comparing the answers to Question 4 (‘Does your organisation have a documented methodology or model for managing projects?’) and Question 5 to see whether the use of a formal methodology in the organisation affects the level of maturity.

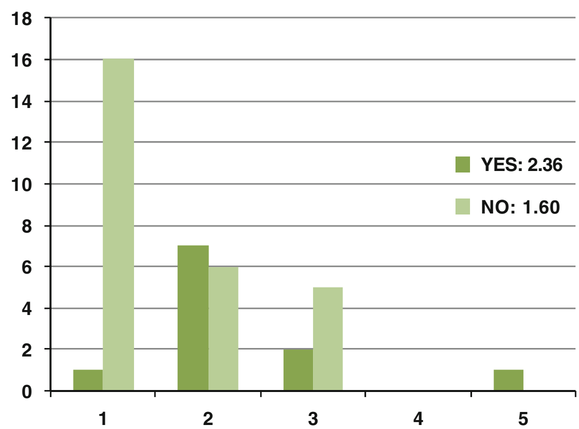


Fig. 7 Formal methodology/maturity level

Looking at Fig. 7 we can see that in this case there is a strong contrast between levels 1 and 2. Organisations that do not use a formal methodology of project management have a lower level (Level 1) than those who use a methodology (Level 2).

We can affirm: the maturity level of an organisation is directly related to the use of a formal and documented methodology for project management.

5 Proposed Maturity Model

We propose guidelines for the development of a new maturity model based on findings from Studies 1 and 2 of this work. We follow the PMBoK guidelines to ensure a common language and focus on the development of a Deming cycle to ensure continuous improvement.

The aim is to remedy the deficiencies identified in Study 1 and meet the needs observed in Study 2. While these proposals will be developed in future work, we specifically propose to meet the weaknesses observed in Study 1:

- Consider the political, social, economic, and cultural aspects in the model;
- Measure staff skills;
- Simplify the procedure and bureaucracy needed to make an evaluation;
- Follow the PMBoK guidelines and vocabulary (5th edition) to ensure a common language.

Study 2 has shown the need to develop a model that assumes a lack of project management knowledge by organisations and is accessible for any size of organisation.

A basic model is proposed that will be later extended to include the three project management dimensions (projects, programs and portfolios).

The starting assumption is that Spanish organisations lack training in this area and have a level 0 of understanding. By building on the Deming cycle, continuous improvement on the road to excellence is assumed—and for this reason it was decided to eliminate a level that was common in almost all the studied maturity models: continuous improvement.

With these assumptions, the suggested maturity model is shown below (Fig. 8).

As shown in the figure above, the Deming cycle rotates as the maturity level rises—'plan, do, check, and act' for all the actions necessary for improved quality are ensured at all stages and situations of the project and organisation. The organisation moves from a lack of unawareness of the tools and techniques of project management (level 0) to process optimisation (level 4), in which all areas of knowledge are evaluated at each level and actions are taken to increase the level.

- No measurement of staff skills;
- Excessive bureaucracy;
- Processes are too long and rigid;
- Use of unknown jargon;

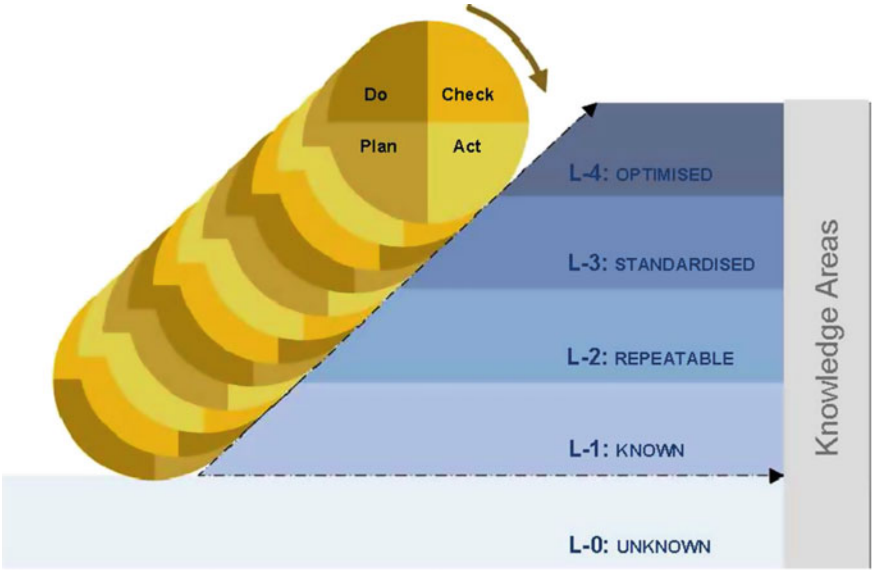


Fig. 8 OM2 functional diagram

Summarised maturity levels in OM2:

Level 0 The organisation is unaware of project management

Level 1 The organisation is aware of project management but no application is made. Projects are undertaken ad hoc. There is a training program for staff

Level 2 The organisation has a portfolio of projects from which lessons are drawn. Several management processes are established and tools are used

Level 3 Project management processes are integrated into a whole and standardised. Cost-time-performance estimates are generally reached

Level 4 Processes towards continuous improvement are reviewed and adapted. The success level is generally 100 %

For the evaluation, the maturity level was obtained for each of the ten knowledge areas established by the PMBoK. The maturity level of the organisation was considered to be the lowest value obtained, as it is considered that a rise in level cannot be achieved until all the requirements in every area are met.

The maturity model is termed the *organisational maturity model* (OM2) and is applicable to all project organisations—even if these organisations are unaware of project management or fail to apply its principles (Fig. 9).

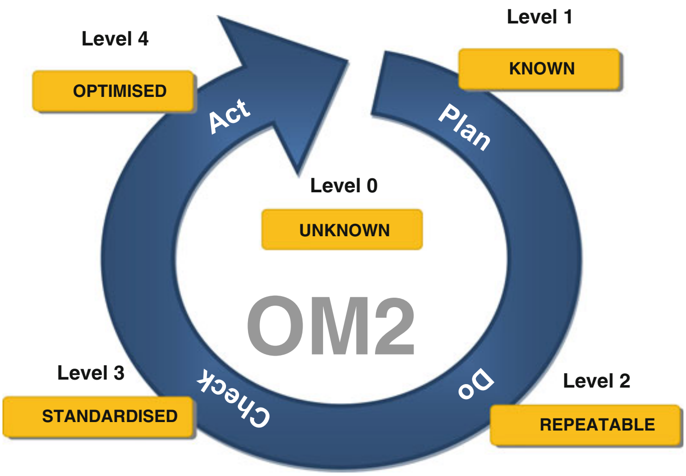


Fig. 9 OM2 model

In summary, OM2 is a maturity model adapted to organisations working with projects of any type and size that wish to make a continuous improvement of their performance by implementing detailed processes and systems—and so ensuring the success of their projects.

6 Conclusions

Following the study of the existing maturity models (Study 1) and an analysis of the current situation of Spanish project organisations through an expert judgment survey (Study 2), we can affirm that Spanish organisations would benefit from a maturity model adapted to the situation found in Spain.

This work has tested seven hypotheses regarding the situation and has established the theoretical basis for a maturity model adapted to meet these requirements —and this model will be developed as future work.

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National Culture and Planning and Control of Projects in Portugal

José Salgado Rodrigues, Alexandra Ribeiro Costa and Carlos Guillén Gestoso

Abstract Previous research report abundantly that management practices are impregnated with national culture, in particular the practices of project management. This is an area with a high impact on the sustainability of countries and organizations, given the importance of efficiency and effectiveness of project management for the economic and social development. This work focuses on attitudes towards planning and control of projects and on practices of these management activities in Portugal. It is based on the application of a survey to 634 professionals involved in implementing and/or managing projects, across the country and in most economic sectors. Although several published studies refer that Portuguese culture attribute low importance to planning and control, the surveyed professionals report a high importance attributed to planning and control of projects. On the other hand, the comparison with a similar study conducted in the USA revealed similar levels of practices of planning and control of projects in these two countries. This is a surprising outcome that raises the possibility of changes happening in the national culture of Portugal.

Keywords National culture · Project management · Portugal

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1 Introduction

The culture of a society or country, i.e., the national culture, understood as the sharing of a story and a set of beliefs, ideologies, traditions and language systems (Alas and Tuulik 2007), or as collective programming (the software of the mind), influences the way people feel, think and tend to act (Hofstede 2001). This programming distinguishes the members of a group or society, and reflects in different areas of our life, such as the arts, social organization, and management as well. No group of people can run away from the effects of culture (Hofstede et al. 2010).

Several authors, such as Baskerville-Morley (2005), criticize some methodological aspects of the research and the findings of Hofstede and his (many) followers. Including the assumption of uniformity of national cultures and the influence of national culture on each individual's or group's effective professional practices.

Although there is no agreement about the concept of national culture and its actual impact on people and their practices, there is a broad consensus on the existence of significant differences between the attitudes and the way things are done in different countries and regions (Smith 2006). Similarly, these differences are believed to also exist in management activities (Cassell and Blake 2012; Javidan and House 2001; Ralston et al. 2008). Management is carried out by people who are imbued with values and beliefs related to the context they belong to. Therefore, it is inaccurate to elaborate on management without considering cultural aspects (Bredillet et al. 2010).

Among the many studies that support this conclusion, Keating et al. (2002) conducted an interesting study comparing practices and values of students and managers in Ireland and Austria. They concluded that there is a high consistency in each of these countries regarding practices and values among Irish students and managers, and among Austrian students and managers. In this study, national culture is more important to characterize practices and values than age or the professional group.

Moreover, project management is influenced by the culture of the countries where the projects are carried out (Bredillet et al. 2010). As stated by Chevrier (2003), projects involving teams with members from different countries are not only international projects, but fundamentally also inter-cultural projects.

The objective of this study is to characterize Portuguese people's attitudes and practices towards project management, specifically towards project planning and control.

2 Background

Projects are very important in our society because the success of organizations (and therefore of the whole economy and the whole society) depends largely on the success of the projects carried out (Shenhar et al. 2001).

Planning and control are two essential management activities, two critical projects' success factors, as emphasized by the extensive literature review conducted by Fortune and White (2006). Kendra and Taplin (2004) emphasize that management processes, specifically planning and control, are basic functions of management, and thus undoubtedly critical factors for project success. Similarly, Elattar (2009) states that planning and control (monitoring) are factors strongly related to project success.

According to results presented by Hofstede et al. (2010), Portuguese culture can be characterized by a large power distance, high uncertainty avoidance, collectivism, femininity and short-term orientation. These authors claim that in countries such as Portugal, holding high power distance and high uncertainty avoidance, planning and control are poorly formalized and poorly systematized.

Cabral (2006), in an empirical study about attitudes and behaviors of the Portuguese population, concludes that there is a high power distance in all the socio-demographic categories of this population. Lopes (2010) conducted a survey on nearly 2,000 executives of Portuguese companies, obtaining results consistent with several features of the Portuguese national culture identified by Hofstede et al. (2010). The author concludes that Portuguese culture is characterized by the propensity to improvisation and individual creativity, with strong contextual conditions of ambiguity (femininity), low capacity for planning, low sense of organization, and a strong trend to create a small group for mutual help (high collectivism). The high power distance leads to a confrontation with an imposing hierarchy, causing an emotional erosion that brings out the improvisation and clandestine self-management.

Several authors relate more specifically about national culture and project management.

Bony (2010) identified significant differences between the way the Dutch and French scientists value and develop project control activities, relating these differences to cultural differences between these two countries. According to Chevrier (2003), there are evidences that national culture is an impact factor on project management, specifically on the planning and control activities. Mohammed et al. (2008) stress the importance of the cultural dimension in project management, as cultural patterns in the environment of a project reflect cultural patterns of organizations, societies and project teams. Zwikael et al. (2005) reported significant differences in the way projects are managed in Israel and in Japan, in both project manager's practices and support systems available in organizations for project implementation.

Some facts suggest that one of the features of Portuguese national culture is the low importance given to planning and control of projects. For example, there are many large public construction projects that are initiated without adequate and realistic plans, and therefore significantly exceed costs and deadlines (Tribunal de Contas 2009). In these and other projects carried out in Portugal, the main causes reported for these deviations are also deficiencies in planning and control (Couto and Teixeira 2006; Monteiro 2010).

According to this background, we formulated two hypotheses:

H1 Portuguese people give little importance to planning and control of projects

H2 Portuguese people have a low level of use of tools and activities for the planning and the control of projects

3 Methodology

Since national culture reveals itself, among other ways, through beliefs and practices (Hofstede 2001), this study uses a survey to assess Portuguese people beliefs and practices in project planning and control?

3.1 The Sample

A survey was conducted, and 634 valid responses were obtained from professionals involved in projects carried out in Portugal over the last 2 years. The respondents were mostly Portuguese (99 %), with high level of education (78 % were graduate or post-graduate) and significant project management experience (70 % had more than 1 year of experience).

As for the organizations where projects were carried out, most had the majority of Portuguese capital (83 %), and represent 19 of the 20 industries classified in the Portuguese economic code of activity. Out of 13 of these industries, 10 or more responses were received.

This sample has a significant dimension, consisting of respondents who appear to be able to comment project management practices in a variety of organizations, industries and projects in Portugal.

3.2 Instrument to Assess the Importance Given to Planning and Control of Projects

The literature review conducted did not allow to find an instrument to assess the importance given to planning and control of projects, an instrument was designed for this purpose. We follow the survey instrument is based on the thought of

Table 1 Instrument to assess the importance given to planning and control of projects

What is your opinion about planning and control of projects? (Please refer to what extent you agree with each statement, by choosing a number from 1 to 5, where 1 corresponds to "Strongly disagree" and 5 corresponds to "Strongly agree")
I1—Planning is one of the most important factors for project success
I2—Planning is important even if there is a careful execution of the project
I3—Control is one of the most important factors for project success
I4—Control is important even if there is a careful implementation of the project

Table 2 Components of the matrix after Varimax rotation

Matrix components	
I1	0.708
I2	0.736
I3	0.721
I4	0.828

Instrument to assess the importance given to planning and control of projects

Hofstede's (2006) when they and Smitth's (2006) by asking, when they argue that the culture of a society or group can be best characterized asking people in that society about the value they attribute to aspects that represent the beliefs in question.

This instrument contains a set of statements about the importance of planning and control for project success. Respondents are asked to express their level of agreement or disagreement. For the development of this instrument, a group of experts in project management was consulted. The following, were the most valued questions for these experts in terms of relevance and representativeness of the importance given to planning and control of projects (Table 1).

The exploratory factor analysis of this instrument (Table 2) allows to conclude that these four items are aggregated into a single factor we call "Importance given to the planning and the control of projects".

The coefficient of Cronbach's alpha for this instrument is 0.72 (Table 3), which indicates a satisfactory degree of consistency of the instrument items. The correlation of each item with the total factor is equal or greater than 0.46. This, which suggests good discriminatory power or internal validity of the items (none of the items, if removed, raises the alpha of the instrument).

The factor "Importance given to the planning and the control of projects" is calculated as the arithmetic mean of the four items forming this factor (I1–I4).

Table 3 Analysis of the items of the instrument to assess the importance given to planning and control of projects

Items	Average	Standard deviation	Ritc	Alpha if item removed
I1	4.68	0.54	0.46	0.69
I2	4.65	0.53	0.49	0.68
I3	4.31	0.70	0.48	0.69
I4	4.32	0.68	0.64	0.58
Importance given to the planning and the control of projects (items average)	4.49	0.50	–	Instrument alpha = 0.72

3.3 Instrument to Evaluate Practices of Planning and Control of Projects

To evaluate practices of planning and control of projects, an instrument proposed by Papke-Shields et al. (2010) was used. This instrument is based on the tools and practices of project management as defined in the Project Management Body of Knowledge (PMBOK) (2008). The PMBOK is the project management standard most used around the world. It is proposed by the Project Management Institute (PMI), which is the largest academic and professional organization in the project management field (Hall 2012).

The PMBOK (2008) divides project management practices and tools into 5 process groups: “Initiating”, “Planning”, “Executing”, “Monitoring & Controlling” and “Closing”. For this research, the relevant practices and tools are those relating to process groups of “Planning” and “Monitoring & Controlling” (control).

This instrument contained 41 items related to process groups of Planning (28 items) and Monitoring & Control (13 items). Each of these items is a tool or practice for planning or control, and respondents are asked how often these tools or practices were obtained or used in the projects they were involved in, in Portugal, in the last 2 years (Table 4). It included other items that have not been considered because they relate to other process groups that are not relevant for this study.

These tools are associated to activities organized in the PMBOK (2008) in 9 knowledge areas: “Project Integration Management”, “Project Scope Management”, “Project Time Management”, “Project Cost Management”, “Project Quality Management”, “Project Human Resource Management”, “Project Communication Management”, “Project Risk Management,” and “Project Procurement Management” (Table 4).

Papke-Shields et al. (2010) applied this set of items to a sample of 142 U.S. project practitioners. The use of the same items on the survey used in this investigation in Portugal allows to compare the responses obtained in these two countries (Table 4).

Table 4 Frequency of use of tools and practices of planning and control of projects in Portugal and in the U.S.A

Based on all projects carried out in Portugal completed in the last 2 years in which you have been involved, please indicate how often the following items were obtained or used				
Knowledge area	Tools and practices of planning and control of projects	Process groups[a]	Average use[b]	
			Sample in Portugal (n = 530–634)	Sample in the USA (n = 142)[c]
Integration	1. Project plan	P	4.01	4.47
	2. Status review meetings	M&C	4.07	4.64
Scope	3. Project deliverables list	P	3.90	4.40
	4. Scope statement	P	3.82	4.27
	5. WBS (work breakdown structure)	P	3.40	3.78
	6. Scope change proposals	M&C	3.17	3.55
	7. WBS update	M&C	3.19	3.28
	8. Scope statement update	M&C	3.18	3.25
Time	9. Project schedule	P	4.10	4.58
	10. Schedule update	M&C	3.77	4.32
	11. Schedule baseline	P	3.72	4.04
	12. PERT or Gantt chart	P	3.34	3.78
	13. Project activities list	P	4.07	4.25
	14. Activity duration estimates	P	3.93	4.16
	15. Activity list update	M&C	3.78	3.64
Cost	16. Cost baseline	P	4.03	3.84
	17. Cost estimate updates	M&C	3.54	3.69
	18. Cost performance reports	M&C	3.47	3.49
	19. Activity cost estimates	P	3.73	3.45
	20. Cost baseline updates	M&C	3.69	3.39
	21. Time-phased budget plan	P	3.46	3.29
Quality	22. Quality checklists	P	3.16	3.08
	23. Defined quality metrics	P	3.20	3.07
	24. Quality management plan	P	3.26	3.01
	25. Quality change requests	M&C	2.84	2.46
Human resource	26. Project staff assignments	P	3.83	4.07
	27. Roles and responsibilities lists	P	3.57	3.74
	28. Responsibility assignment matrix	P	3.38	3.34

(continued)

Table 4 (continued)

Based on all projects carried out in Portugal completed in the last 2 years in which you have been involved, please indicate how often the following items were obtained or used				
Knowledge area	Tools and practices of planning and control of projects	Process groups[a]	Average use[b]	
			Sample in Portugal (n = 530–634)	Sample in the USA (n = 142)[c]
	29. HR change requests	M&C	2.89	2.17
Communications	30. Communication management plan	P	2.91	3.39
	31. Information distribution plan	P	3.01	2.92
	32. Communication requirements analysis	P	2.87	2.65
	33. Communications change requests	M&C	2.63	2.44
Risk	34. Risk management plan	P	3.02	3.31
	35. Contingency plan	P	2.88	3.13
	36. Risk register	P	2.92	2.60
	37. Quantitative risk analysis	P	2.73	2.59
	38. Risk register updates	M&C	2.75	2.51
Procurement	39.. Contract statement of work	P	3.65	4.00
	40. Supplier evaluation criteria	P	3.58	2.96
	41. Procurement management plan	P	3.28	2.87
Planning items—average use			3.46	3.56
Monitoring and controlling items—average use			3.31	3.29
Global average use			3.41	3.47

Standard deviation values are not displayed. The data from United States was not obtained for this study
[a]*P* Planning; *M&C* Monitoring & Controlling
[b]*1* Never; *2* Seldom; *3* Sometimes; *4* Frequently; *5* Always
[c]*Source* Papke-Shields et al. (2010, p 655)

4 Results

The obtained results were unexpected.

Contrary to what is stated by other authors addressing this issue, as shown in Table 3, Portuguese respondents refer giving high importance to planning and control of projects. Although results in other countries were not available for comparison, the absolute levels of the responses are very high: the factor "Importance given to the planning and the control of projects" has the value of 4.49

on a scale of 1–5, where “5” represents the agreement among all respondents regarding the high importance of planning and control for project success.

Consistent with these responses, results regarding the frequency use of used tools and practices to plan and control projects is also high. For the 41 items regarding tools and practices for planning and control, respondents report that in the projects they were involved in, suena mejor the projects in which they participated in the last 2 years, the average utilization rate was 3.41 on a scale of 1–5, where “1” corresponds to “Never” and “5” corresponds to “Always” (Table 4).

More surprisingly, this result is similar to the result obtained by Papke-Shields et al. (2010) in an survey that includes the same 41 items of tools and practices of project planning and control applied to 142 professionals involved in the management of project management, members of a PMI Chapter of eastern United States (Table 4). Contrary to what might be expected, the overall use of management tools for planning and controlling projects reported by respondents in these two countries is very similar. Given that, and being the USA, unlike Portugal, a country bearing cultural characteristics of low power distance and low uncertainty avoidance (Hofstede et al. 2010), one would expect the project planning and control processes in the United States to be more formalized and more systematized than in Portugal.

Both hypotheses of this study were rejected, since the results show that in Portugal people give high importance to planning and control of projects (H1), and there is a very frequent use of the tools and activities of planning and controlling of projects (H2).

5 Discussion and Conclusions

Previous studies about Portuguese national culture concluded that there is a reduced emphasis on planning and control, and a reduced use of these management practices. These characteristics are expected to be identified also in project management practices in Portugal. The results of this study did not validate this assumption.

According to Hofstede (2007), national culture tends to be stable over time and to resist the changes that are currently taking place in different societies.

However, Taras et al. (2012) reached different conclusions. These authors conducted an analysis of data collected from more than 400 studies of the 1980s, 1990s and 2000s, using national culture models compatible with the four dimensions model, presented by Hofstede in (1980): power distance, individualism versus collectivism, masculinity versus femininity and uncertainty avoidance. They balanced the indices obtained by Hofstede in (1980) with the results of other studies in that same decade, and calculated indices for the next two decades based on studies in those decades. They concluded that in several countries there is a considerable variation over time in the scores of these national culture dimensions. Regarding the Portuguese national culture, this study shows an increase of individualism and a decrease of power distance, femininity and uncertainty avoidance over three decades.

As referred by Fang (2006, p. 88), culture, like the oceans "… has no boundaries, and its various waters are both separate and shared, both different and similar, and both independent and dependent". Economic and cultural globalization influences national culture (Bird and Stevens 2003; Shah 2009). Also the integration of Portugal in the European Union, where people, goods, services and information can easily move across borders, certainly contributes to the increase of the influence of several other national cultures in Portugal.

More specifically concerning project management, the study carried out by Bredillet et al. (2010), based on the Hofstede's national culture model, correlates the culture and the economic development with project management development in 74 countries. According to these authors, Portuguese national culture characteristics (low individualism, high uncertainty avoidance and high power distance) favor a reduced development of project management. However, in the same study Portugal is placed among the 24 countries with higher development of project management, ahead of countries like France and Belgium. Also Gomes et al. (2008) reported a good level of knowledge of the characteristics and important variables of effective project management practices based on a sample of project managers of Portuguese government organizations.

The results of this study contradict some of the conclusions of previous studies about the importance given by the Portuguese to planning and control. In this specific perspective, the results do not confirm the characteristics of the Portuguese national culture presented by several authors. These results suggest the possibility that a change is occurring in the importance that Portuguese people give to planning and control, which is also reflected in project management practices in Portugal. This change may be associated with a change in the Portuguese national culture, since this hypothesis has also been raised by other authors.

It will be useful to conduct more studies to test this hypothesis, given its important implications.

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Part II
Civil Engineering, Urbanism and Urban Planning. Building and Architecture

Calculating the Carbon Footprint of the Household Urban Planning Land Use

S. Zubelzu and A. Hernández

Abstract The present paper presents a methodology to incorporate carbon footprint calculation in the urban planning process. Using the developed methodology for residential land use, the general scope is defined, the sources are identified, and greenhouse gas emissions are calculated for several municipalities in the south of Madrid, which amounts which amounts to 6.609 tCO_{2eq}/dwell.yr. A set of 31 municipalities in Madrid was analyzed to quantify its greenhouse gas emissions, which vary between 165.23 and 147543.32 tCO_{2eq}/yr. The relations between the emission of greenhouse gases and urban design parameters and the aptitude of the non-developable land to fix projected emissions, varying from 3.18 to 24.55 hectares of non-developable land were studied. **Resumen** En la presente comunicación se expone una técnica para la incorporación del cálculo de la huella de carbono en los procedimientos urbanísticos. Se ha definido el contexto general, identificado las fuentes y cuantificado las emisiones vinculadas a los usos residenciales para un conjunto de municipios en el sur de la Comunidad de Madrid, que se han cifrado en 6,609 tCO_{2eq}/viv•año. Se han estudiado también las relaciones entre las emisiones y los parámetros de diseño urbanístico y la aptitud de suelo no urbanizable para fijar las emisiones previstas oscilando los ratios entre las 3.18 y las 24.55 hectáreas de suelo no urbanizable.

Keywords Greenhouse gas · Carbon footprint · Diffuse emissions · Urban planning

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1 Introduction

The role of municipalities in reducing the diffuse greenhouse gas (GHG) emissions has become notably relevant. Among the types of diffuse GHG, transport, residential, residues, commercial and certain industrial activities are included.

There are two types of measures that municipalities can adopt to manage GHG emissions. First, the corrective measures directed to reduce the GHG emissions of the current activities in the city. The second type are preventive measures that can be executed through urban planning.

The first group of measures has often been promoted as shown in Sovacool and Brown (2010), Puliafito and Allende (2007) or Dhakal (2009). Conversely, preventive studies related to the GHG emissions that can be generated from urban projects are not common.

Urban planning has a decisive influence on GHG emissions in general (Engel et al. 2012) and on diffuse emissions in particular, because it puts in order transportation, urban uses and waste management.

The main advantage of linking the GHG emission assessment to urban planning is that it simplifies the implementation of preventive measures for their reduction and compensation based on urban design decisions. Examples of these types of measures can be found in Dong et al. (2013) regarding industrial developments, Kim and Kim (2013) regarding dwelling building intensity, Ho et al. (2013) regarding urban design, Wu et al. (2013) on coefficient cities, and La Roche (2010) examined certain building solutions.

Therefore, the main objective of this paper is to develop a methodology to calculate the carbon footprint that is linked to residential use and can be implemented through urban planning instruments.

2 Methodology

The urban planning master plan was selected because it is the urban planning basic standard that applies for the entire municipality area. After the planning instrument was selected, the methodology applied required the definition of theoretical framework (characterization of the GHG emission sources and determination of the consumption and the emission factors) and the assessment of GHG emissions. As a practical complement to this, the carbon footprint of the actual planning has been studied on a set of 31 municipalities in the south of the Community of Madrid.

2.1 Theoretical Framework

The theoretical framework require specifying the agent of the GHG emissions around which calculations can be made. Thus, ignoring the particularities in regulations and doing the necessary simplifications, a general urban development plan must define the land occupation model, other structuring determinations and the management conditions.

The land occupation model requires the assignment the entire municipality area to a land use category (urban, developable or non-developable land). This model evidently affects the resultant carbon footprint by identifying those urban lands where GHG will be generated, and those that will be excluded from urban planning and are potentially apt to fix emissions.

This land occupation model is tightly linked to managerial conditions, since the conditions for urbanizing developable land are established and those responsible for carrying on this development are identified (urban sector). They are responsible for the urban development and fit the role of responsible agent for the calculation of carbon footprint in the terms defined by the British Standards Institution (2008).

Regarding the other structuring determinations, as an overall plan, global uses and utilization and the public network should be defined. The edification intensities clearly affect GHG emissions because they usually determine the type of specific activities to be executed in every land use category and the intensity with which it used. The former have an evident influence on the carbon footprint and vouch for the identification of sectors as responsible agents, by defining the uses in each sector (residential, industrial, tertiary) and the intensity (utilization).

Communication systems, equipments, infrastructures and open spaces networks and green spaces are usually included among the public network.

It can be assumed that the green spaces do not generate GHG emissions, while the equipment, in any form it may be presented, can be considered as another land for the calculation of the carbon footprint. The communication systems and infrastructure have a clear impact on the carbon footprint; however, emissions are not caused by them but by the final customers.

2.2 Emission Sources

The identification of GHG emission sources must be centered on the agent responsible for the calculation of those emissions. Thus, each sector will be defined on the general plan by the use and utilization of the land and the conditions for its development. The first two, do not generate GHG emissions but affect the type of sources (uses) and the intensity of emissions (utilization). The development conditions do not generate emissions either and allow for the implementation of preventive measures.

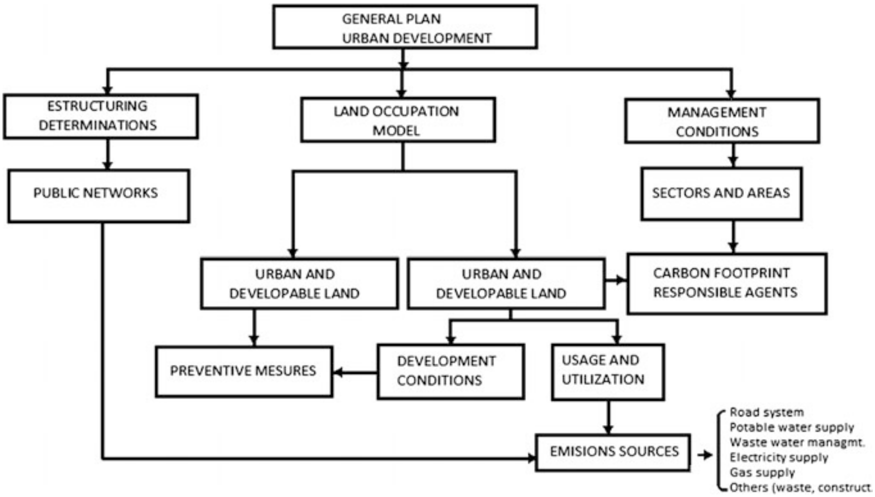


Fig. 1 Theoretical framework of GHG emission calculation in the general urban development plan

The global land use and built intensity determine the GHG emissions, and the standard development allows one to implement preventive measures.

Then, in order to identify the GHG emission sources, the public networks that provide services to the sectors included on the general planning (road network, water supply, electricity, sanitation and gas), from which use emissions are generated, must be studied.

The scheme in Fig. 1 summarizes the aforementioned theoretical framework.

2.3 *Carbon Footprint Calculation*

The carbon footprint is calculated using the following equation:

$$\mathrm{HC}\left(\mathrm{kgCO}_{2\mathrm{eq}}\right) = \Sigma \mathrm{C_i}(\mathrm{units}) \times \mathrm{FE_i}\left(\mathrm{kgCO}_{2\mathrm{eq}}/\mathrm{units}\right) \quad (1)$$

Consumption data (C_i) were collected from secondary information sources, which required contrasting data from different sources. The emission factors (EF_i) were referred to the CO_2 equivalent, (CO_{2eq}) which includes the equivalence in terms of CO_2 for all GHG.

The estimated emission factor published by the Oficina Catalana de Cambio Climático (OCCC 2014) for 2013, was used, according to which the emission factor of the peninsular electricity generation mix was 0.248 $kgCO_2eq/kWh$. The considered emission factor for direct consumption of natural gas in housing is 0.2

$kgCO_2eq/kWh$ (MARM 2011), whereas the emission factor for vehicles is 0.20487 $kgCO_2eq/km$ (Zubelzu et al. 2011). A rate of 2.9 residents per house (INE 2013) was considered to homogenize the data that were measured with different units. This rate was calculated for the Community of Madrid in the population and housing census by the Instituto Nacional de Estadística (INE 2013).

3 Results and Discussion

The following sections show the results using the theoretical framework for the carbon footprint calculation linked to residential use and the analysis made for the studied region.

3.1 Theoretical Calculation

The results of the carbon footprint calculation of every analyzed source are shown in the following sections.

3.1.1 Potable Water Supply

Figure 2 shows the procedure to calculate the carbon footprint of potable water consumption.

According to the Instituto Nacional de Estadística (INE 2014) the average consumption of potable water is 145 l/inhabitant. The energy cost of the potable water supply was analyzed by several authors (Table 1).

The average value proposed by Hardy and Garrido (2010) was used, because it is best adapted to the local conditions in the analyzed area. Therefore, the annual energy cost of the potable water supply per person in the Community of Madrid is 53.98 kWh. Then, the resulting carbon footprint is 13.78 $kgCO_{2eq}$/yr.

3.1.2 Wastewater Management

The process to calculate the carbon footprint of the wastewater management is shown in Fig. 3.

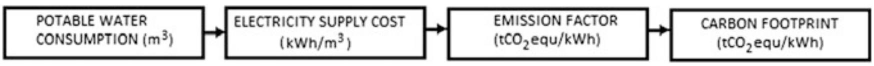


Fig. 2 Methodological scheme for the calculation of the carbon footprint of a potable water supply

Table 1 Energy cost of the drinking water supply by different authors

Author		Energy intensity (kWh/m^3)		
		Lower limit	Average	Upper limit
California energy commission (2005)		0.21	–	8.25
Salas (2007)	Surface catchment	0.0002	–	1.74
	Groundwater catchment	0.37	–	1.32
	Desalinization	4.94	–	5.41
Cabrera et al. (2010)		0.13		0.31
Hardy and Garrido (2010)		0.23	1.02	6.99
Qi and Ni-Bing (2013)		–	1.29	–

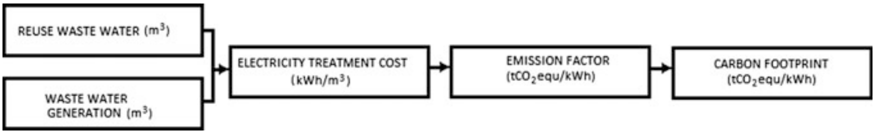


Fig. 3 Methodological scheme for calculating the carbon footprint of domestic wastewater management

The amount of treated wastewater per inhabitant and day in Madrid is 0.22 m^3 according to INE (2014), which fits approximately the published results of IECM (2014) that calculates it as 0.2 m^3/d. The amount of reused water is 0.0022 m^3/inhab. d (INE 2014). The calculated energy costs of wastewater treatment and reuse are shown in Table 2.

There are other detailed works that allow the analysis of the carbon footprint of different wastewater treatments (RodríguezGarcía et al. 2012), but the results are usually close to the data in Table 2. The average values proposed by Hardy and Garrido (2010) were again chosen for being the ones best adapted to local conditions.

Table 2 Energy cost of wastewater management according to different authors

Author	Purification energy cost (kWh/m^3)			Reuse energy cost (kWh/m^3)		
	Lower limit	Average	Upper limit	Lower limit	Average	Upper limit
California energy commission (2005)	0.29	–	1.33	0.11	–	0.32
Cabrera et al. (2010)	0.36	–	0.8	0.2	–	0.43
Hardy and Garrido (2010)	0.41	0.58	0.72	0.32	0.57	0.85
Qi and Ni-Bing (2013)	–	0.976	–	–	–	–

Therefore, the annual carbon footprint of the wastewater treatment is 11.55 $kgCO_{2eq}$/yr, and the carbon footprint of reusing is 11.66 $kgCO_{2eq}$/yr.

3.1.3 Electricity

The calculation of the carbon footprint resulting from electricity consumption requires applying the corresponding emission factor to the measured consumption. (Figure 4).

According to Comisión Nacional de la Energía (2011) and IDAE (2011), electricity provides energy to household appliances, lighting and air-conditioning systems, whereas the kitchen, heating and hot water are supplied with natural gas. Thus, a typical dwelling so defined, consumes 2,746.47 kWh/yr in peninsular Spain (IDAE 2011) which produces a carbon footprint of 234.87 $kgCO_{2eq}$/yr.

3.1.4 Gas Supply

The scheme to determine the carbon footprint derived from gas consumption is shown in Fig. 5.

According to the Comisión Nacional de la Energía (2011), the average gas consumption per year in the Community of Madrid varied in 2010 between 10.26 and 13.5 MWh/dwelling, whereas The Federación de la Energía de la Comunidad de Madrid (FENERCOM 2011) calculated it at 8,9 MWh/dwelling (considering a total consumption of 1,347 ktep (15,103,827 kWh) and 1,691,467 clients).

Thus, considering as valid the intermediate consumption of 10.26 MWh the resulting carbon footprint is 707.58 $kgCO_{2eq}$/yr for each inhabitant.

3.1.5 Transportation Infrastructure (Road Traffic)

The carbon footprint of transportation was calculated by using the information referring to the characteristics of movements and an estimate is made by applying

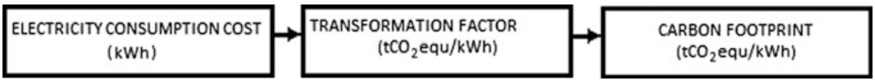


Fig. 4 Methodological scheme for calculating the carbon footprint of the electricity consumption

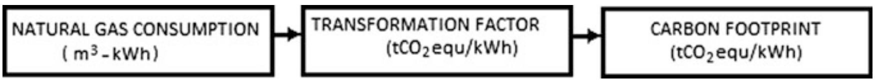


Fig. 5 Calculation scheme of the carbon footprint of the gas consumption

the corresponding emission factors. According to Monzón de Cáceres and De la Hoz (2009), the average length of mandatory travel rose in 2004 up to 10.3 km while the non-mandatory rose up to 5.7 km, both referring to the Community of Madrid. Using those distances, and supposing that the mandatory movements are made on working days (250 days/yr), the resulting annual emissions due to road traffic was 661.18 $kgCO_{2eq}$/yr.

3.1.6 Other Emissions

1. Waste treatment

The scheme to determine the carbon footprint of waste treatment is shown in Fig. 6.

There are certain problems at this point because of the various available treatment technologies, the diversity of residues generated, the difficulty of typifying waste generation and the scarcity of reliable information sources regarding waste management. Thus, the aggregated data is used, on total emission generation and GHG generation, included in the Greenhouse Gases Emission Inventory (MARM 2011), which reports in 2008 a value of 15,560,000 tCO_{2eq} as a result of 27,462,704 tons of treated waste. Those values imply a rate of 0.56 tCO_{2eq}/t of treated waste, which is slightly higher than the values reported by Romero et al. (2010) (0.341 tCO_{2eq}/t in Barcelona) or Mühle et al. (2010) 0.2844tCO_{2eq}/t in United Kingdom and 0.103 tCO_{2eq}/t in Germany. The average of those data referring to Spain will be taken, resulting in 0.45 tCO_{2eq}/t of residue.

Thus, the resulting carbon footprint generated from residue treatment is 198 $kgCO_{2eq}$/yr per inhabitant, considering that every inhabitant produces 0.44 tons of waste per year in the Community of Madrid (INE 2013).

2. Building

Several authors have studied the carbon footprint of the building process (Suzuki and Oka 2011; La Roche 2010; Onat et al. 2014, Strobele 2013). Given their nature, the total carbon footprint must be distributed along the building lifetime (50 years). La Roche (2010) calculated an annual total carbon footprint of 1.061 tCO_2eq/dwelling, which represents 0.365 tCO_2eq per inhabitant. Espelt and Adarve (2009), calculated a carbon footprint for the edification and urbanization construction processes of 15,221 kg/inhab. and 871 kg/inhab. respectively, for an urban model in Barcelona. These values indicate a total carbon footprint of 0.321 tCO_2eq/inhab. yr.

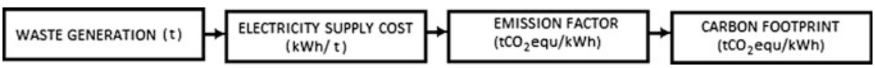


Fig. 6 Methodological scheme to calculate the carbon footprint of waste management

The average of the pair the mentioned values, which is 343.32 $kgCO_{2eq}$/inhab. yr. can then be taken as valid.

3. Other emissions

Several GHG emissions are not attributable to the aforementioned sources: public lighting, street cleaning, and city maintenance, among others. For their calculation, assigning a percentage of the total emissions is accepted as valid. Some authors (Lin et al. 2013; Ramaswami et al. 2008) consider a value of 10 % which includes every GHG emission source and not only the urban-planning-related ones, whereas on this study a value of 5 % was considered.

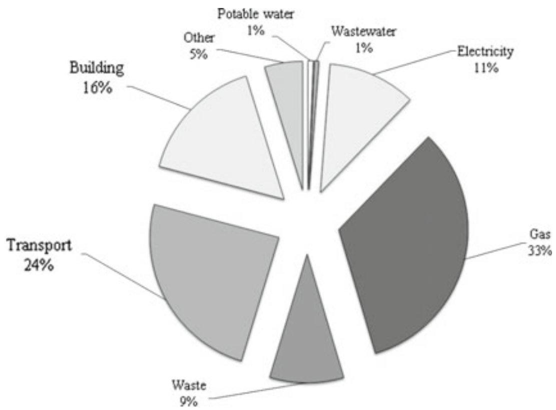
3.1.7 Summary of Emissions

Finally, the carbon footprint of the urban land for dwelling construction use is calculated as follows, considering number of dwellings and expected occupation.

$$
\begin{aligned}
\mathrm{HC}\left(\mathrm{kgCO_{2eq}/yr.}\right) &= 1.05 \times [\mathrm{HC_{water}} + \mathrm{HC_{wastewater}} + \mathrm{HC_{elect.}} \\
&\quad + \mathrm{HC_{gas}} + \mathrm{HC_{build.}} + \mathrm{HC_{roadtraffic}} + \mathrm{HC_{inhab.}}] \\
&= 1.05 \times 2,170.5\left(\mathrm{kgCO_{2eq}/inhab.}\right) \\
&\quad \times \mathrm{Oc(inhab./dwelling)} \times \text{Number of dwellings}
\end{aligned}
\tag{3.1}
$$

The final results of the carbon footprint calculation for the analyzed area are shown in Fig. 7.

Figure 7 shows that the most important source is the gas, followed by transportation, being water the least influential one. The deduced global carbon footprint



	GHG emissions ($kgCO_2$/pr·yr)	GHG emissions ($kgCO_2$/res·yr)
Potable water	13,78	39,97
Wastewater	11,66	33,83
Electricity	234,87	681,12
Gas	707,59	2.052,00
Waste	198,00	574,20
Transport	520,50	1.509,45
Building	343,42	995,92
Other	101,49	294,32
Total	2.131,31	6.180,81

Fig. 7 Summary of the carbon footprint calculation

value per inhabitant is consistent with the results of other authors. Lin et al. (2013) and Ramaswami et al. (2008) stated that the carbon footprint of the sources studied in their work, being 12 big cities, (20.97 % of the total carbon footprint calculated by these authors) oscillated between 4.3 and 0.996 tCO_{2eq}/yr for Denver and Tokyo. Minx et al. (2013) calculated the carbon footprint of 434 municipalities in the United Kingdom, reaching an average per inhabitant of 12.5 tCO_{2eq} which implies 2.61 tCO_{2eq}/yr considering the 20.97 % from the sources that are comparable to this study. Petsch et al. (2011) obtained 19.5 tCO_{2eq}/yr, whereas Jones and Kammen (2013) obtained 20 tCO_{2eq}/yr in the United States.

The similarity among the results of the present study and the aforementioned consumption-based works confirms the validity of the theoretical calculations.

3.2 *Case Study in the Community of Madrid*

The deduced methodology was applied to a set of municipalities in the south of the Community of Madrid (Fig. 8).

Table 3 shows the results, obtained by applying the deduced methodology to the studied municipalities.

The results in Table 3 show that higher GHG emissions come from Valdemoro, Navalcarnero and Aranjuez (exceeding the amount of 100,000 tCO_{2eq}/yr), whereas the lower amounts do not exceed 1,000 tCO_{2eq}/yr (Valdaracete, Villamanrique de Tajo and Cadalso de los Vidrios).

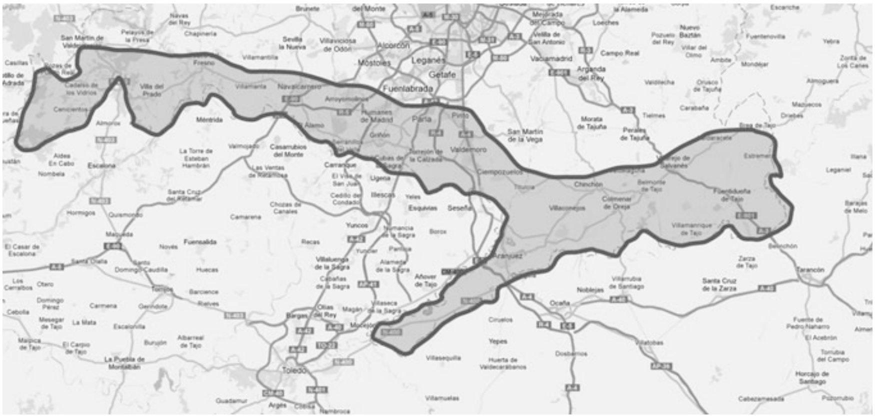


Fig. 8 Location of the analyzed municipalities

Table 3 Urban planning parameters for the analyzed municipalities

Municipality	Dwelling units	Urbanizable area (ha)	Total carbon footprint (tCO_{2eq}/yr)
Estremera	2,098	116	13866.06
Fuentidueña de Tajo	1,291	184	8532.45
Valdaracete	150	13	991.38
Villarejo de Salvanés	3,037	113	20072.08
Villamanrique del Tajo	112	4	740.23
Belmonte del Tajo	405	20	2676.72
Valdelaguna	444	29	2934.48
Chinchón	175	6	1156.61
Titulcia	732	34	4837.92
Ciempozuelos	6,529	366	43151.33
Aranjuez	15,917	1,656	105198.31
Valdemoro	22,324	615	147543.32
Torrejón de Velasco	3,913	154	25861.72
Pinto	3,789	82	25042.18
Parla	9,316	393	61571.12
Humanes de Madrid	872	22	5763.20
Torrejón de la Calzada	2,384	83	15756.28
Griñón	839	78	5545.10
Cubas de la Sagra	3,268	216	21598.80
Casarrubuelos	1,352	52	8935.61
Moraleja de Enmedio	1,077	70	7118.09
Serranillos del Valle	1,747	109	11546.24
Batres	423	28	2795.68
Arroyomolinos	8,818	367	58279.74
El Álamo	2,724	352	18003.40
Navalcarnero	20,325	528	134331.57
Villamanta	811	64	5360.04
Aldea del Fresno	664	49	4388.50
Villa del Prado	1,086	81	7177.57
Cadalso de los Vidrios	25	1	165.23
Cenicientos	362	22	2392.52

Note The information in Table 3 has been extracted from the Community of Madrid cartographic information (http://www.madrid.org/cartografia/planea/planeamiento/html/visor.htm). It may not correspond exactly with the current planning, as all specific modifications have not been considered. Numbers of definitive dwellings or growth intended areas and built areas may not exactly match with the resultant figures after the developing planning, because on occasions these numbers have been estimated from urbanistic design parameters such as edificability or urban use

4 Conclusions

A methodology to calculate the carbon footprint of residence land use integrated in the urban planning was presented. The methodology was developed based on a research on emission sources attributable to urban planning.

The consumption was quantified and the corresponding emission factors were applied and the resulting carbon footprint was calculated to be 6.60918 tCO_{2eq}/yr per planned dwelling unit on the general urban development plan. The consumption of natural gas and transportation are the most pollutant sources, both comprising nearly 60 % of the total GHG emissions.

Moreover, as a complement, an equation to calculate the carbon footprint was deduced that incorporates the amount of dwellings and expected occupation as the only independent variables.

Regarding the case study, the results show that the emissions exceed 100,000 tCO_{2eq}/yr on those municipalities with greater growth.

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Part III
Product and Process Engineering and Industrial Design

Methodology for the Selection of Key Performance Indicators for Sustainable Steel Production Through an Intelligent Control System Use

J.M. Mesa Fernández, F. Rodríguez Pérez, G.M. Martínez Huerta and S.M. Andrés Vizán

Abstract Steel production is involved in a continuous improvement process forced by customers to enhance product quality as well as to reduce production costs. Moreover, both society and the regulators increase their pressure to reduce the environmental of this activity, so the decision process has necessarily to include the environmental perspective. This communication proposes the concept of an Intelligent Control System (ICS) to assist the optimization of the production process of steel in a holistic way, considering quality, economic and environmental parameters. Processes environmental evaluation are based on the definition of Key Performance Indicators (KPIs) susceptible to be managed online by the ICS and this communication is devoted to the development of a methodology for KPI selection. Then, the procedure is applied to a case study, the Hot Strip Mill, and after its systematic application, a collection of KPIs based on GHG emissions monitoring and suitable to be managed automatically and in real time is proposed.

Keywords Steel · Intelligent control system · Hot strip mill

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1 Introduction

Nowadays, steel production is under growing pressure to improve the quality of the products, reducing production costs at the same time. This entails that deviations in the quality of products must be detected as soon as possible; therefore, steel producers must observe and classify the product throughout the entire production chain, and take decisions regarding the most suitable future use of the product and, as a consequence, also regarding the treatments which intermediate materials must undergo to achieve it. To date, the Decision Support Systems (DSS) developed for the steel industry are targeted to assist operators in resolving problems of production planning. Fedáková and Marek presented in 2003 a DSS called OKO to assist the business decision making in a steel mill based on the SAS statistical system (Fedáková and Marek 2003). Other publications describe applications used in specific processes and shows a DSS for the planning of the Hot Strip Mill (Cowling 2003) or optimize the cost of iron ore mixture for the Blast Furnace (Zhang et al. 2011).

The environmental issue, generally speaking, is an aspect which is not usually present in the current DSS developed for the steel industry. At the moment, the environmental aspects are taken into consideration at the highest levels of decision hierarchy, and this results in business policies aimed to comply with the current legislation or establishing benchmarking initiatives between the different plants at the most, but without any influence on the production of individual products. The only DSS found in the literature is the one described by Spengler et al. in (1998), where a combination of models are applied in a multicriteria analysis to assess and classify the different alternatives for recycling dust and sludge. However, the steel production has come under increasing pressure to take into account environmental aspects in its decision-making process. For instance, CO_2 emissions reduction certificates or the energy rate are partly responsible for the increasing in the prices of steel products and, in the medium term, it is likely that the decisions made will have to take into account those aspects to produce steel products at a competitive price and with an acceptable environmental impact.

A way to optimize the industrial processes is the use of second generation Decision Support Systems, known as Intelligent Control Systems (ICS), which receive real-time information from many production variables, that process and assess automatically and comprehensively, following decision rules and/or other support systems. They are also used for automatically adjusting the manufacturing process or providing the operator with the guidelines to follow to achieve the optimization of the production according to a set of predetermined criteria.

This paper aims at developing a methodology of selection of **Environmental Performance Indicators** which will be the grounds for the environmental assessment of steelmaking processes, with the target of being part of an ICS to assist in the decision making process of steel production, along with technical and marketing criteria such as the quality of the final product and production cost; at the

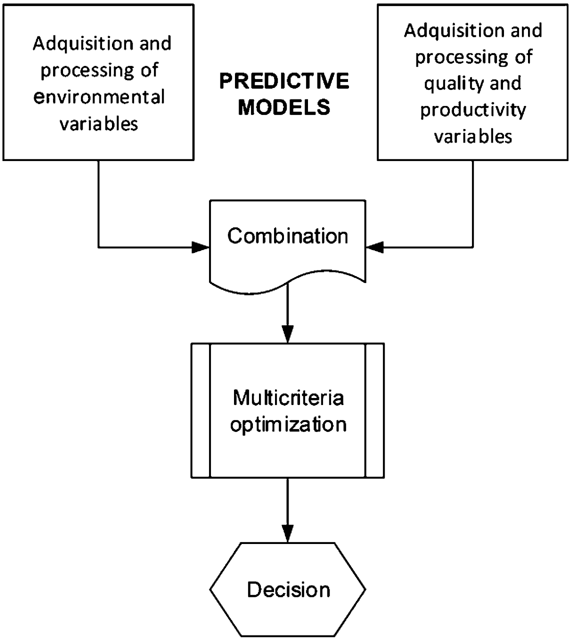

Fig. 1 General concept of intelligent control system

same time, it considers the environmental impact of production to try to diminish it in real time.

To provide the context for the methodology of process environmental assessment, the general concept of an ICS which will meet the requirements previously exposed is displayed in Fig. 1

The Intelligent Control System consists of two modules. The first one assesses quality and productivity according to physical and chemical measurements of the final and intermediate products. Also, according to predictive models, It establishes such input is suitable for the determined final product or, on the contrary, if it deviates rounding up or down, from the suitable conditions. The second module assesses the environmental impact of the final product according to a series of data extracted from the process variables, which it is constantly receiving.

The results obtained by both modules are combined afterwards, following a multicriteria strategy of optimization which, meeting a set of predetermined requirements, will decide if such input should be reassigned to another final product or rejected, in case of not meeting the quality standards. At the same time, except in the last case, the ICS will provide the operator with indications of the treatments to undergo, as well as the adequate way to perform them for the product to arrive with the demanded quality and optimal environmental impact and cost efficiency.

2 Environmental Assessment of Steelmaking Processes with an Intelligent Control System

The data to be used by the Intelligent Control System for the environmental analysis must not only reflect the environmental condition of the process, but must also be in a format that allows their automated processing. Therefore, data must be objective as well as measurable.

The environmental impact of the systems is calculated by the ICS following the input/output methodology. This methodology is widely used in the assessment of environmental impact and it is currently gaining more acceptance because it is largely used for the carbon footprint analysis and other options of Life Cycle Assessment (LCA). Each process is characterized by its own environmental assessment, where it is scored according to the nature and intensity of the use of resources, for example electricity consumption as well as emissions and waste generated. Once a product comes out of a process, it is assigned a set of values which reflect the environmental condition of such process. After that, this intermediate product undergoes the following process, where again the environmental condition values are calculated, and then, they are added to the ones it carries from previous processes. This added value corresponds to the one of the full system.

The Environmental Performance Indicators or KPIs (Key Performance Indicators) present de adequate characteristics to be used by a ICS, since they are indexes dedicated to numerically describe and monitor the environmental performance of a system, organization or process. They are quite useful for the environmental assessment since they measure relevant parameters and quantities which simplify complex varieties, providing easily understood information on the environmental condition of the entity is being analyzed (Andrés 2005). Moreover, when the information of the KPIs is analysed and reported periodically, it allows to detect trends and apply corrections in case of unsatisfactory results (MMA 1996). Popular examples of KPIs outside the steel sector are the tons of equivalent CO_2 emissions in the atmosphere or acres of land dedicated to ecological agriculture.

3 Methodology for the Selection of KPIs for the Assessment of the Sustainability of Steelmaking Processes

An indicator is efficient, when it comes to reflecting an environmental condition, if it meets the following requirements (Australian State of the Environment Committee 2006):

- Relevant for the measured parameter
- Understood involved parties in its use. It must be clear and unambiguous.

- Based on trustworthy information
- Transparent and verifiable calculation
- Based on specific conditions.
- Must fully represent the object of study

While an indicator refers to a specific environmental problem, KPIs are generally grouped into sets of indicators commonly known as indicator systems, which represent a sorted set of environmental problems concerning a precise industrial activity (MMA 2000). Since the environmental issues are usually multidimensional, and therefore cannot be analyzed with a single indicator, before developing KPIs to be included in the SCI, a system of indicators should be formalized to ensure that a manageable number of indicators covers all relevant categories. It represents a good practice to use generic indicator systems as a starting point for the designing of a specific indicator system. In the case of the steel industry in Spain, the following systems of generic indicators are particularly relevant:

- IHOBE System (1999)
- GRI System (Global Reporting Initiative) (2002)
- IISI Sustainability Indicators (World Steel)

Generic indicator systems are individually compared? and then it is carefully verified if every environmental aspect of steel production is taken into account and duplicities are avoided, as explained in Fig. 2.

Once the indicator system is formalized, all flows in each process are studied in such a way that all parameters relevant for environmental assessment and subject to be reflected by indicators, are identified, since not all inputs and outputs have a

			Classification IHOBE/ISO/EMAS																						
			Operational Performance									Performance Management								Environmental Status					
			Input			Equipment & Facilities			Output			System				Functional Area				Environ. performance			Biosphere & Anthrop.		
			Materials	Energy	Products & Services	Infrastructure	Land Use	Transport	Products & Services	Waste	Emissions	Application of policies and programs	Conformity	Financial performance	Employee participation	Administration and planning	Purchases & investments	Health & Safety	Community relations	Air	Water	Land	Wildlife	Human	Cultural Heritage
Classification GRI	Economic	Economic performance												X											
	Environmental	Materials	X																						
		Energy		X																					
		Water																			X				
		Biodiversity																				X	X		X
		Emissions, Effluents & Waste								X	X									X					
		Products & Services							X	X															
		Compliance													X										
		Transport						X																	
		Overall															X								
	Social – Labor/Mang. Relations	Occupational Health & Safety																X						X	
		Training & Education													X										
	Social – Society	Community																	X						
		Public Policy										X				X									
	Social – Product Responsibility	Health & Safety to client											X												
		Product & Service Labeling											X												

Fig. 2 Example of comparisons of generic indicator systems

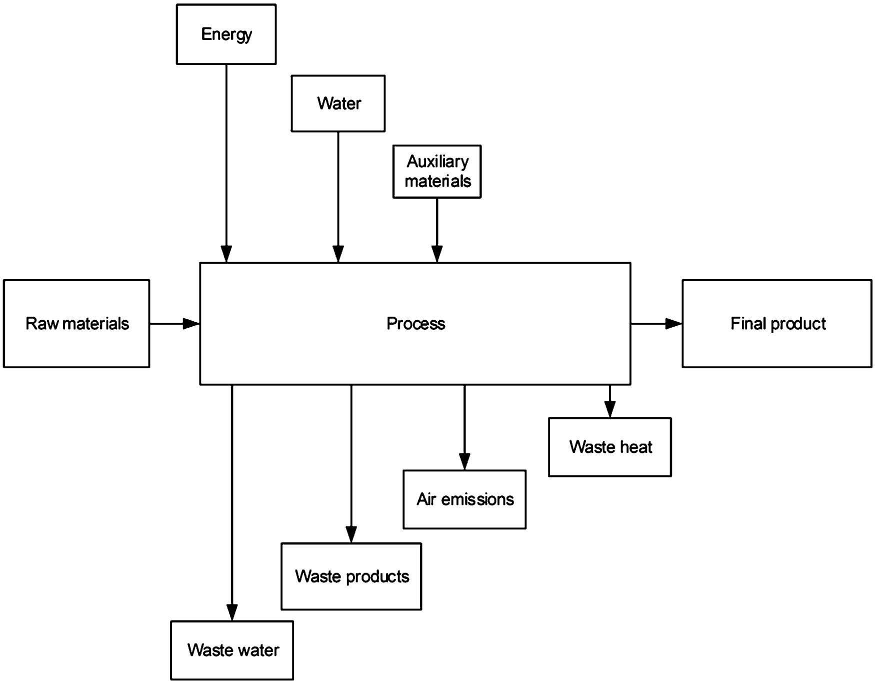

Fig. 3 Generic mass flow chart for steelmaking processes

relevant influence on the final result. Each process is characterized by a mass flow chart where all inputs and outputs are detailed, as generically exemplified in Fig. 3.

Once all flows are identified, the parameters with no significant influence on the environmental assessment of the process are removed. Such task demands to model the whole process in order to see which ones are the relevant flows. Such modelling can be performed with the methodologies commonly used for Life Cycle Impact Assessment (LCIA) such as the following:

- ReCiPe
- IMPACT 2002
- USEtox
- TRACI

After the analysis of the contribution of each process flow, the most relevant ones are identified and their structure, calculation, measure units and calculation periodicity are formalized.

4 Implementation in a Particular Case

The previous developed methodology will be applied to the case of steel coil production in the Hot Strip Mill (HSM).

The HSM transforms the slabs coming from the casting line into coils with width and thickness according to specifications from the client. The Initial slab thickness is approximately 220–250 mm, whereas, after going through the hot strip mill, the thickness of the slab is about 1.5–2.0 mm.

The main parts of a HSM are the reheating furnaces, where the slab temperature is raised, the roughing mill, which performs the double function of scale treatment (rupture and disposal) and scale rolling, to obtain sheets of intermediate thickness between the slab and the final sheet. It is then sent to the finishing mill where, once it cropped, its thickness will be reduced until the desired thickness for hot coil is reached. Finally, the thin sheet is sent to the spinning machines where it is threaded.

The environmental implications of an intermediate or final product cannot be assessed without consideration to the process they are generated from. On the contrary, they must be treated in a holistic way, since those aspects such as, for instance, the origin and production routes taken by raw materials do have a major influence on the environmental impact of the final product. However, although the methodology presented in the previous chapter is applicable to the steel industry in general? the process of collecting and analyzing data for the steelmaking process as a steelmaking will consume a great deal of time and resources, not worth the implementation for the implementation of ICS in one isolated installation. Therefore, in this case it has been chosen to perform an analysis in two levels:

- On the one hand, the route of the product through the manufacturing process is extracted from the plant historical data
- On the other hand, the assessment at the HSM is made in more detail, considering all options available, both at operator and management levels.

4.1 Modelization of the Head-End Process

Figure 4 shows the head-end process before reaching the Hot Strip Mill.

As Fig. 4 shows, the extraction and transportation of the raw materials to the factory already generates a great amount of environmental impact. This is due to the nature of mining and the technology used in the extraction process, as well as the distance and means of transportation used to bring them to the plant. as well as the distance and means of transport used to bring them to plant. After that, iron ore fines are processed in the sinter plant using coke, which has been produced using coal coming from the same coke plant, or imported. This step of the process also generates an environmental burden. The sintered material is then sent to the Blast Furnace where it is processed along with other raw materials and more coke to

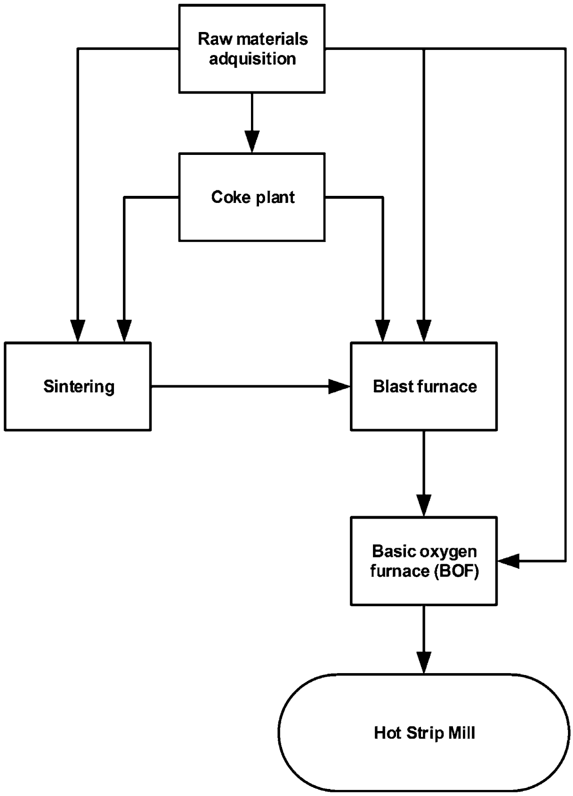

Fig. 4 Flow chart of steelmaking process until HSM

produce pig iron. The impact is calculated and added to ones already mentioned. Then, the pig iron is sent to the converter, in the shape of slabs, to produce steel. This way, the production of coils in the HSM has the slabs as the main raw material, and its environmental burden has been calculated according to the route production, the resources consumed, emissions and waste generated.

In order to model the environmental performance of all possible combinations of the sheet treatment that may occur in the HSM, the input/output analysis of the installation is performed in a comprehensive manner. To this end, the influence of each of the environmental parameters involved in the process is assessed, in order to determine which ones should be reflected in the assessment indicator system and which should not be considered as they are not relevant enough.

Next, Fig. 5 displays a chart of all input and output flows of the process of the HSM which may be considered for environmental assessment:

From the previous concept, quantifiable inputs and outputs are extracted, which are then used for the environmental assessment of the HSM in Table 1:

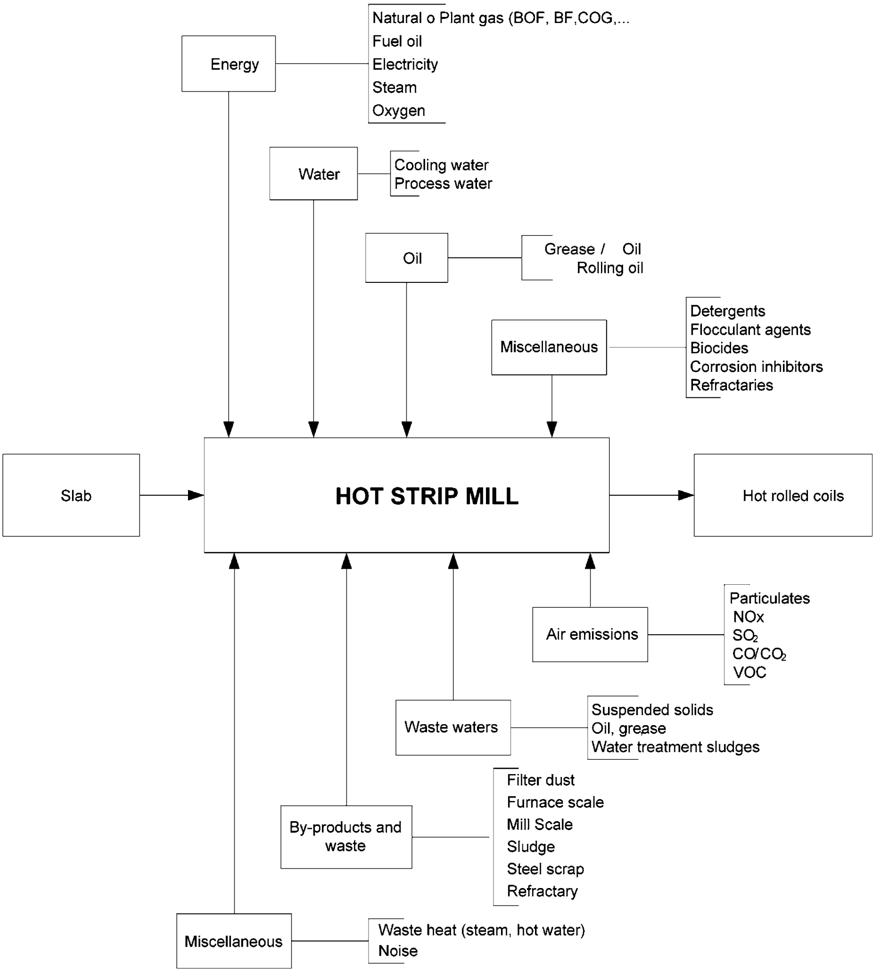

Fig. 5 Flow chart of HSM

4.2 Selection of KPIs for the Environmental Assessment of a Hot Strip Mill

The definition of a Functional Unit (FU), namely, that scale which all indicators refer to, is a previous step to the their definition. In the case of the HSM, there are two possible options:

- Ton of steel as a slab when going into the HSM
- Ton of coil produced when leaving the HSM

Table 1 Inputs and outputs of the HSM installation

Hot rolling mill			
Inputs		Outputs	
Reheating furnace			
Energy	GJ/t rolled steel	Dust	g/t rolled steel
Cooling water	0 (closed loop)	NO_X	g/t rolled steel
		SO_2	g/t rolled steel
		CO	g/t rolled steel
		Hydrocarbon	g/t rolled steel
		Furnace scale	kg/t rolled steel
Descaling			
Waste water	m^3/t rolled steel	Waste water	m^3/t rolled steel
Energy	kWh/t rolled steel	Oil free	kg/t rolled steel
		Oily scale	kg/t rolled steel
Rolling and lubrication oil			
Water	m^3/t rolled steel	Particulates	g/t rolled steel
Energy	kWh/t rolled steel	Filter dust	g/t rolled steel
		Fugitive oil emissions	negligible
		Waste water	m^3/t rolled steel
		Sludge	m^3/t rolled steel
		Metallic by-products (crops, rejections, cuttings…)	kg/t rolled steel
Waste water treatment plant			
Process water	m^3/t rolled steel	Discharged water	
Flocculating agents	kg/t rolled steel	Total suspended solids	g/t rolled steel
Others	kg/t rolled steel	Chemical oxygen demand	g/t rolled steel
		Hydrocarbon content	g/t rolled steel
		Water treatment sludge	kg/t rolled steel

Given that the roughing process implies material losses, it was decided to choose ton of coil as FU. This selection process is common to input/output analysis.

Comparison with specific environmental impact databases for the steel sector shows that the environmental impact of most of the parameters shown in Table 1 is insignificant if compared to the impacts of energy consumption during the process. When we apply the lifecycle impact assessment method called ReCipe (perspective and standardization H/H) to process database EcoInvent 2.01 Hot Rolling, Steel (EcoInvent 2007) the results show that the categories of climate change (impact on ecosystems and human health) are 32 % of the total impact of the activity of HSM, and the category of depletion of fossil resources is 61 %. In addition, Table 2 shows how the production of hot rolled coil is a significant contributor to CO_2 emissions in the steelmaking process. Therefore, given that greenhouse effect emissions are a direct result of energy consumption, it is estimated that they can adequately summarize the environmental performance of the activity and are taken as an indicator of reference for the environmental assessment of the HSM.

Slab reheating and the reduction of thickness of the sheets are the most energy-consuming processes in the HSM, the first one being the most intense in consumption, since the limit of elasticity of the sheets is reached under high temperatures..

Another major energy consumer in the HSM not being considered in Table 2 is the loss of material productivity, which should be considered for the environmental assessment. Some other forms of material loss have been already taken into account during the calculation of energy consumption, for example, the metal being processed during the hot rolling process gets cold and must be reheated, which in the end increases the energy consumption. However, excluding some exceptions, this phenomenon is not taken into account since it is very difficult to quantify; therefore, it cannot be included in the ICS. Much more relevant is the loss of Fe2+ at the different stages of production, due to the fact that during the whole steelmaking process there are heavy losses because of process failures, oxidation, dust formation, etc. Its effect on emissions depends on the point of the process where the losses are produced and how much energy was wasted during production until that point was reached. For instance, the Fe2+ which is lost during rolling is normally re-melted, so emissions increase around 2.3 kg CO_2/ton of steel every 1 % loss (in weight) of Fe2+. However, the loss of material often occurs later in the process when further additional energy has been invested in the steel production. If the slab must be reheated and hot rolled, the scrap generated produces an increase of 5.9 kg

Table 2 CO_2 emissions for each of the stages of production of a hot rolled coil (Fruehan et al. 2000)

Process	CO_2 (kg/t product)	CO_2 (%)
Hot metal	1500	82.4
Liquid steel	200	11.0
Hot rolling	120	6.6
Hot rolled coil	1820	100.0

Table 3 CO_2 emissions for each of the stages of production of a hot rolled coil (Fruehan et al. 2000)

Process	Type of loss	CO_2 (kg/t)
Hot metal	Hot metal loss to slag but recovered	1.6
Hot metal	Hot metal loss to slag not recovered	11.6
BOF	Fe vaporized to dust	2.6
BOF	Fe ejected to dust	2.8
Hot rolling	Fe lost but recovered	2.3
Cold rolling	Reheating for hot rolling but recovered	5.9

CO_2/t. If the iron is oxidized or not recovered, the energy invested in steel is also lost. A loss of 1 % applied to the most likely cases of production represent an additional loss of 1.4 kg CO_2/t fusion energy in the converter. Table 3 shows an estimate of kg of extra CO_2 emitted into the atmosphere due to material losses in various parts of the steelmaking process.

From what has been said it can be concluded that most relevant factors to consider when assessing the environmental performance of HSM are the ones related to energy consumption and material losses, since they determine the greenhouse effect emissions during the process. Therefore, the KPIs selected for environmental assessment of HSM are shown in Table 4.

Since the emission values are not directly measurable, the environmental assessment would be performed through online monitoring of energy consumption of the machinery involved, and the equivalence with CO_2 emissions is calculated from the data shown in Table 5:

Table 4 KPIs selected for the environmental assessment of HSM

Name	Formula	Unit
Material use	100*t slab/t coil	%
Fe recovered	100*Kg Fe recovered/kg Fe lost	%
Total GHG generation	Kg CO_2/t coil	kg/t
Deformation GHG	kg CO_2(forces)/t coil	kg/t
Heating GHG	kg CO_2(heating)/t coil	kg/t

Table 5 Emission factors of the different energy sources for the HSM (Fruehan et al. 2000)

Fuel source	Emission factor (kg CO_2/MJ)
Coke	0.109
Natural gas	0.050
Hydrogen	0
Electricity	0.173
Coke oven gas	0.046

5 Conclusions

Industrial processes, specially the steelmaking process, constantly aim to increase their productivity while reducing their environmental impact. The inclusion of the environmental component into the systems of production assistance would minimize this impact. Therefore, the manufacturing, quality and economic variables are not the only decision factors to consider in the production process.

In this paper, a methodology is proposed for the selection of environmental indicators to be used in an Intelligent Control System.

Afterwards, this methodology is validated by its application in the case of a Hot Strip Mill, which shows that:

- Most of the impacts are a consequence of the energy consumption
- The value of greenhouse effect gas emissions is proposed as an indicator of the environmental performance of the process.

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Design and Optimization of a Chassis for an Air-Assisted Sprayer with Two Fans Using the Finite Element Method

H. Malon, F.J. Garcia-Ramos, M. Vidal and A. Bone

Abstract The use of plant protection products such as pesticides to protect crops against attacks by fungi, insects and weeds is a common agricultural practice. The affected areas have to be treated uniformly and with the appropriate concentration. This is achieved by the use of agricultural machinery such as air-assisted sprayers. The most common air-assisted sprayers have only one fan on the rear. This implies that the airflow generated around the machine is not symmetrical. Consequently, it is not possible to ensure the same quality of treatment for all trees. The installation of a second fan and the increase in tank capacity in the machines have resulted in machines with greater dimensions. These machines have to support higher loads compared to traditional air-assisted sprayers. The development of these new designs of air-assisted sprayers requires optimization of their chassis in order to ensure the proper operation of these agricultural implements. The main objective of this study is the design and optimization of a chassis for an air-assisted sprayer equipped with a 4000 l tank and two axial fans.

Keywords Design · Optimization · Chassis · Air-assisted sprayer · FEM

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1 Introduction

The use of plant protection products such as pesticides to protect crops against attacks by fungi, insects and weeds is a common agricultural practice. The purpose of using pesticides is to obtain healthier crops and increase production per unit of cultivated area. In order to ensure a successful treatment, farmers have to choose the correct products and ensure that the pesticides reach all areas of the plant affected by the pestilence. These affected areas have to be treated uniformly and with the appropriate concentration. This is achieved by the use of agricultural machinery such as air-assisted sprayers.

In this study, the researchers focus on air-assisted orchard sprayers, which are used in most tree plantations.

Air-assisted sprayers are machines (mostly dragged by a farm tractor) equipped with a tank where the plant protection product is dissolved in water. The capacity of the tank depends on the model and the manufacturer; however, it usually ranges from 0.5 to 5 m^3 Fig. 1.

The most common air-assisted sprayers have only one fan on the rear. This implies that the airflow generated around the machine is not symmetrical. Therefore, the treatment carried out on either side of the agricultural implement is not equal. Consequently, it is not possible to ensure the same quality of treatment for all trees. (Herrington et al. 1981; Cross 1991; Doruchowski et al. 1997). In recent years, some manufacturers of air-assisted sprayers have installed two fans on their machines to resolve this problem. The use of two fans allows the airflow generated by the agricultural implement to be symmetrical on both sides of the machine. Moreover, in some cases, the interaction of the airflows generated by the two fans induces a turbulent flow regime that facilitates the distribution of the protection products on the crops. In this sense, using two fans can have a positive effect to ensure a successful treatment.

The installation of a second fan and the increase in tank capacity in the machines have resulted in machines with greater dimensions. These machines have to support

Fig. 1 Air-assisted orchard sprayer

higher loads compared to traditional air-assisted sprayers. The development of these new designs of air-assisted sprayers requires optimization of their chassis in order to ensure the proper operation of these agricultural implements.

2 Objective

The main objective of this study is the design and optimization of a chassis for an air-assisted sprayer equipped with a 4000 l tank and two axial fans (Fig. 2). The two fans rotate in opposite directions. One of the fans is located in the rear of the chassis (as in currently existing machines) and the other fan is installed in the front of the chassis.

Numerical techniques based on the Finite Element Method (FEM) were used in the development process. These techniques allowed the simulation of the typical loads expected for this type of agricultural implement. In particular, the numerical simulations allowed analysis of the stiffness and resistance behaviour of the chassis, and thus, they facilitated the optimization of the chassis.

The secondary objective of this study is to design a new chassis model using only folded sheets. This objective implies that is not possible to utilize commercial structural profiles in the construction of the chassis.

3 Numerical Analysis of the Chassis of an Air-Assisted Sprayer

Numerical analysis carried out by means of the FEM is a technique frequently applied for the design and optimization of chassis for trailers, trucks, machinery, and agricultural implements. (Beermann 1984; Kodiyalam and Sobieszczanski-Sobieski 2001; Karaoglu and Kuralay 2002; Cappello et al. 2005; Li et al. 2007;

Fig. 2 Air-assisted sprayer with two axial fans with reverse rotation

Valladares et al. 2009; Carrera et al. 2010; Miralbes and Castejon 2010; Deng et al. 2011; Hoefinghoff et al. 2011; Miralbes et al. 2011; Vidal et al. 2011).

In this study, FEM was used in the design and optimization of a chassis for an air-assisted sprayer.

Load cases corresponding to normal operational manoeuvres of an air-assisted sprayer were analysed. The selected manoeuvres are the most critical to the chassis as per the resistance and stiffness criteria.

3.1 Finite Elements Model

A finite element model of a chassis for an agricultural implement with a 4000 l tank and two axial fans was developed. Figure 3 shows the discretized model developed in this study.

The discretized model was developed using the design dimensions of a commercial model, which was provided by the company GARMELET S.L.

In order to obtain the correct simulation of the load cases, it was necessary to model a 4000 l tank. The final finite element model (Fig. 4) consists of 76,614 nodes and 77,421 elements.

The components of the chassis used in the discretized model were all shell-type elements with the exception of the hook bolt and the crossbeam on which the wheels are placed. These two components of the model were discretized with volumetric elements.

The two fans and the reducing group of the air-assisted sprayer were replaced in the numerical model by mass elements, which were placed at the centre of mass of the cited components. The mass values introduced into the numerical model correspond to the actual mass of the components replaced. These mass elements were attached to the chassis of the agricultural implement in their anchor points by means of multi-point constraints (MPC's).

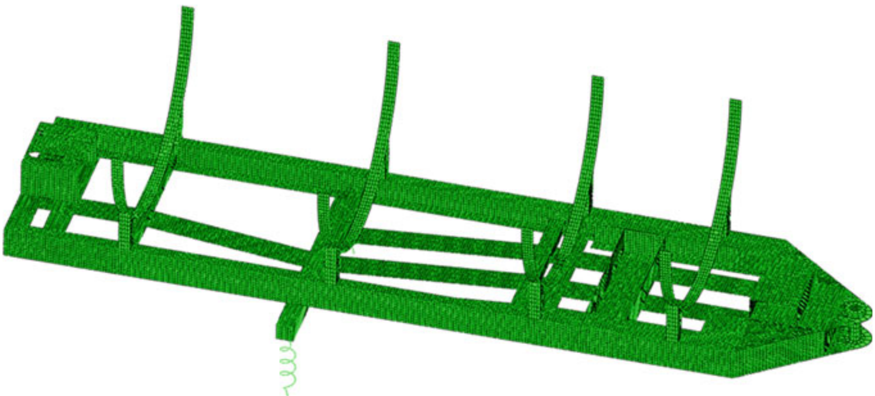

Fig. 3 Numerical model of the chassis for an air-assisted sprayer

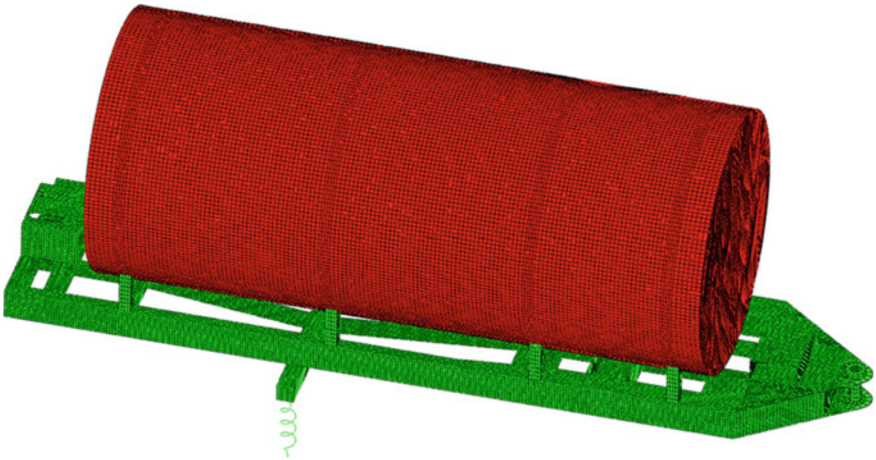

Fig. 4 Full finite elements model of the chassis for an air-assisted sprayer

Materials used in the numerical analysis based on FEM were S275-JR and S235-JR steels, whose mechanical properties were obtained from the EN 10025-2006 standard. The materials distribution in the chassis is shown in Fig. 5.

3.2 Boundary Conditions

In order to reproduce the behaviour of the chassis during the manoeuvres analysed, the research group defined a series of boundary conditions for the numerical calculations that reproduce realistic boundary values.

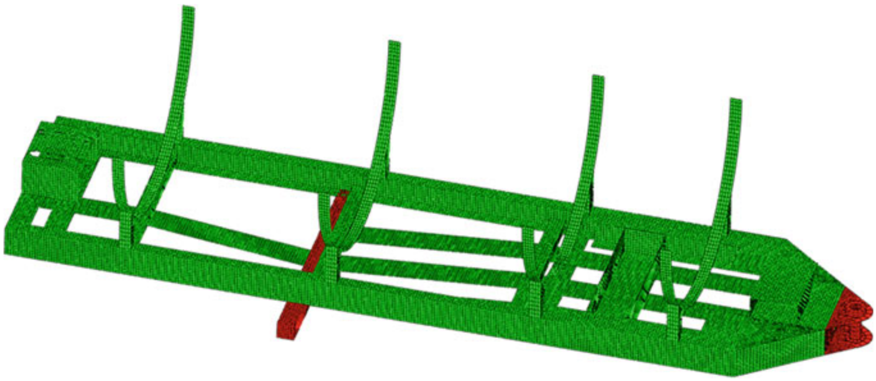

Fig. 5 Materials distribution in the chassis

First, displacement in the hook bolt, which is placed in the front of the chassis, was constrained in all directions.

Second, the wheels of the air-assisted sprayer were replaced by springs that reproduce the behaviour of the wheels. The upper nodes of the springs were allowed vertical displacement and rotation; however, they were constrained in movements in the horizontal plane parallel to the ground. The lower nodes of the springs that simulated the contact between wheels and the ground were constrained in all displacements.

3.3 Load Cases

Load cases analysed in the study corresponded to the, 'chassis at rest', and the five most critical load cases for evaluating the structural resistance of the chassis. The load cases analysed are described below. Unless otherwise noted, a hydrostatic pressure was defined in the inner walls of the tank to simulate the load of 4000 l in the tank.

The first load case, 'chassis at rest', corresponds to the situation in which the implement loaded with 4000 l of liquid is attached to a stationary tractor as shown in Fig. 6.

The second load case analysed, 'initial impulse', corresponds to the manoeuvre in which the air-assisted sprayer tank is full and the tractor starts to move. At this moment, a force is created on the hook bolt. The maximum value of this force is generated at the previous instant to overcome the force of static friction on the wheels. The maximum value of the drag force was calculated from reactions obtained in the wheels of the load case, 'chassis at rest'.

The third load case, 'inclination +5°', corresponds to the manoeuvre in which the tractor and the air-assisted sprayer are not in the same horizontal plane. In particular, the agricultural implement is rotated 5° counter-clockwise with respect to the rear axle of the tractor. This manoeuvre occurs when the implement continues to climb a ramp while the tractor has already completed the climb. In this manoeuvre,

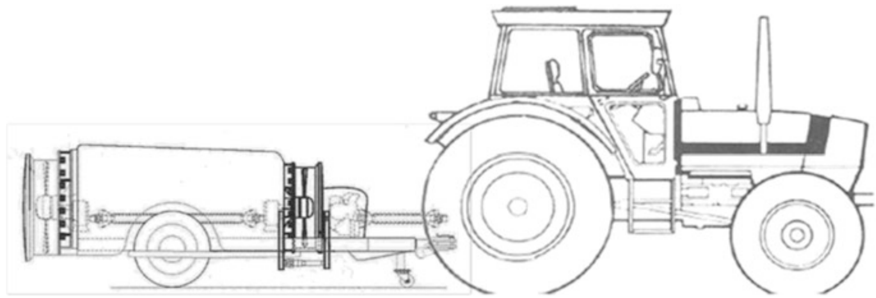

Fig. 6 'Chassis at rest'

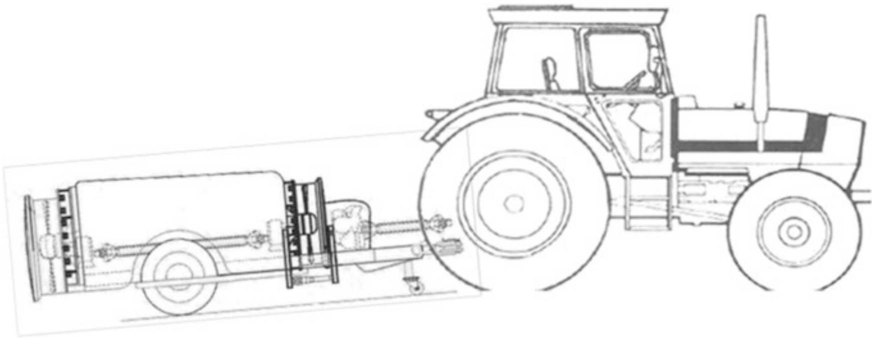

Fig. 7 ‘Inclination +5°’

the wheels of the air-assisted sprayer are supported at a height lower than the wheels of the tractor. The configuration of the tractor-implement ensemble for this load case is shown in Fig. 7.

The fourth load case, ‘inclination −5°’, corresponds to the manoeuvre in which the tractor and the air-assisted sprayer are not in the same horizontal plane. In particular, the agricultural implement is rotated 5° clockwise with respect to the rear axle of the tractor. This manoeuvre occurs when the implement continues to descend a ramp while the tractor has already completed the ramp. In this manoeuvre, the wheels of the air-assisted sprayer are supported at a height higher than the wheels of the tractor. The location of the tractor-implement ensemble for this load case is shown in Fig. 8.

The fifth load case analysed, ‘lateral inclination’, occurs when one of the wheels of the air-assisted sprayer is raised to overcome an obstacle. In this manoeuvre, the agricultural implement turns around its longitudinal axis, which generates a variation of the load distribution on the chassis. This study analysed the case in which one of the wheels overcame a 100-mm high obstacle. To simulate this, a vertical displacement of 100 mm was imposed on the bottom node of one of the springs that simulate the wheels in the numerical model.

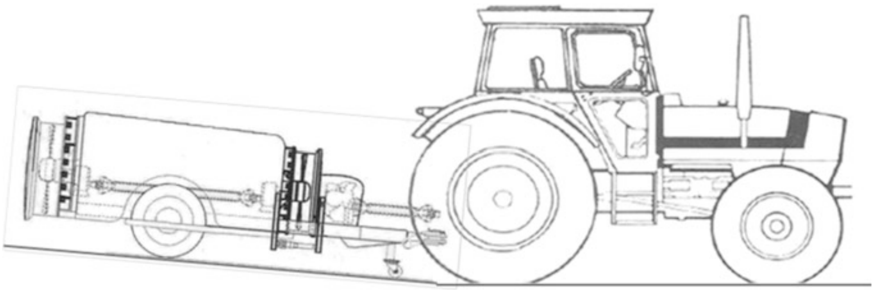

Fig. 8 ‘Inclination −5°’

The sixth and final load case analysed, ‘swell’, occurs when the tank is not fully loaded and is one of the most critical load cases for the integrity of the chassis and the tank. In this situation, the acceleration of the tractor generates waves in the tank, which impact against the rear and front walls of the tank. This study simulated the case of a sudden braking manoeuvre. When the brakes are applied, the fluid moves to the front of the tank and impacts the front wall. In this simulation, the tank is filled to half its capacity. In addition to hydrostatic pressure, a force equivalent to the force generated by a 2000 l load in a 1 G braking manoeuvre is applied on the upper half of the front wall of the tank.

4 Numerical Analysis Results

After the finite element model of the chassis for an air-assisted sprayer was developed, the researchers performed calculations for the load cases described previously. This section shows the results of the FEM for both the initial design and the optimized design of an air-assisted sprayer chassis.

The optimization process was carried out based on stiffness and resistance criteria.

4.1 Initial Design of the Chassis

Once the numerical calculations of the chassis initial design were finished, the obtained results were analysed in order to optimize the geometry of the chassis components.

Numerical calculations provided Von Mises stress and displacements of the global model as well as each component of the chassis separately. Figure 9 shows the Von Mises stresses obtained from the load case, ‘swell’, which is the most critical for the global structure from the point of view of resistance.

The vertical displacements obtained from the load case, ‘lateral inclination’, are shown in Fig. 10. This load case is the most critical for the global structure from the point of view of stiffness.

Once the results were analysed, the maximum value of the Von Mises stresses was obtained for the load case ‘lateral inclination’. In this load case, the maximum value of stress was located in the axle, whereas in the other load cases, the maximum value of stress was located in the support arches of the tank. The maximum value of stress generated in the axle of the wheels in the load case, ‘lateral inclination’, was an effect of the boundary conditions imposed on the numerical calculation.

A safety coefficient was used to facilitate the optimization process. Figure 11 shows the minimum safety coefficient of the initial chassis components for all load cases.

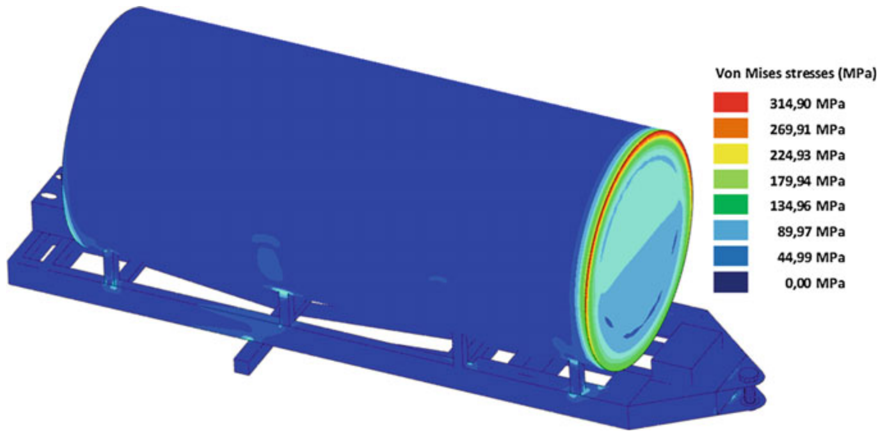

Fig. 9 Von Mises stresses obtained from the load case, 'swell'

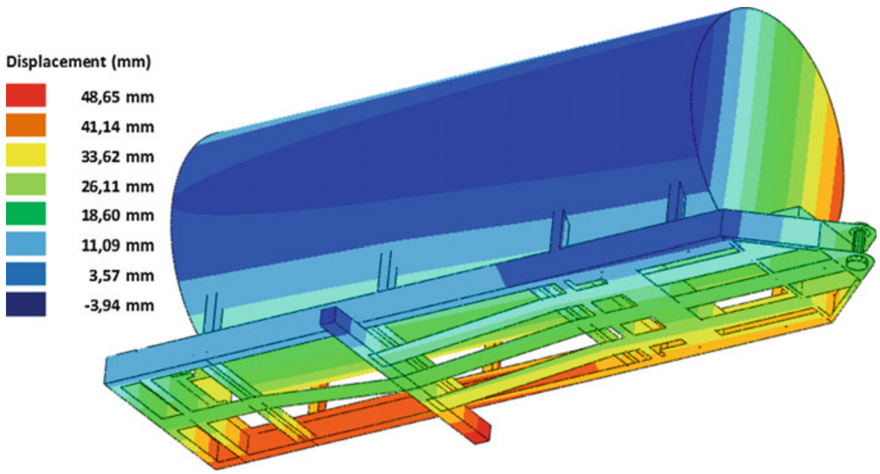

Fig. 10 Vertical displacements obtained from the load case, 'lateral inclination'

4.2 *Optimized Design of the Chassis*

The second phase of the study consisted of optimizing the chassis design. The optimization process was based on the minimum safety coefficient obtained from the numerical analysis of each component of the initial chassis.

For components with a safety coefficient between 1 and 1.5 (in red in Fig. 11), the researchers concluded that the maximum values of stress were either very localized or due to the boundary conditions imposed. For these reasons, the research group decided not to modify these components.

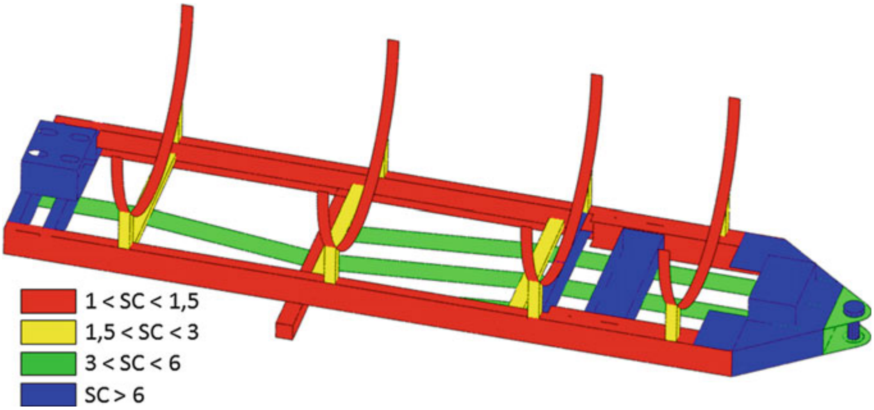

Fig. 11 Minimum safety coefficient of the initial chassis components

For components with safety factors between 1.5 and 3, the researchers decided to maintain the initial configuration. This was decided because the stresses obtained were not problematic according to the resistance criteria and reducing the thickness of the components was not possible.

The thickness of components with a safety coefficient greater than 3 was reduced. For some components, this reduction was 50 % of the initial thickness.

Figures 12, 13 and 14 show a comparison of the Von Mises stresses obtained from the three worst load cases: 'initial impulse', 'lateral inclination', and 'swell'.

In the figures, the variation of stress distribution is similar in the initial model and in the optimized model. In addition, the maximum values of Von Mises stresses are practically equal in both models. Therefore, the optimized model could be validated according to the resistance criterion. Similar to the initial model, Fig. 15 shows the minimum safety coefficient of the optimized chassis components for all load cases.

The optimized components had reduced safety coefficients. These components changed from values exceeding 6 to values between 3 and 6. In addition, the optimization process reduced the mass of the chassis by 97.2 kg, which is a mass reduction of 18.50 % with respect to the initial model.

5 Conclusions

In the present study, an air-assisted sprayer chassis was designed and optimized. The chassis was equipped with a tank of 4000 l and two axial fans.

The initial model was designed according to the dimensions of an agricultural implement of similar characteristics, which was provided by the company GARMELET S.L.

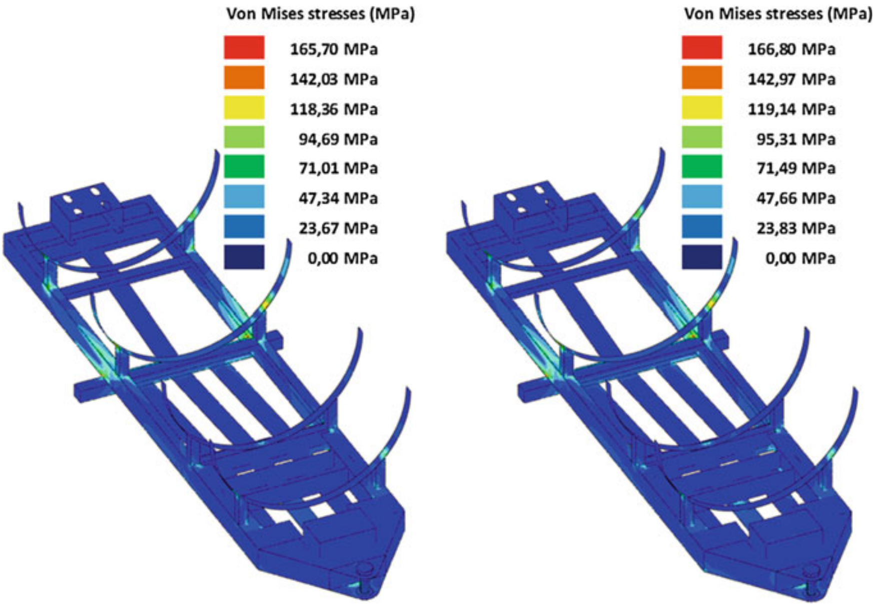

Fig. 12 Von Mises stresses obtained from the load case, 'initial impulse' (*left*—initial design, *right*—optimized design)

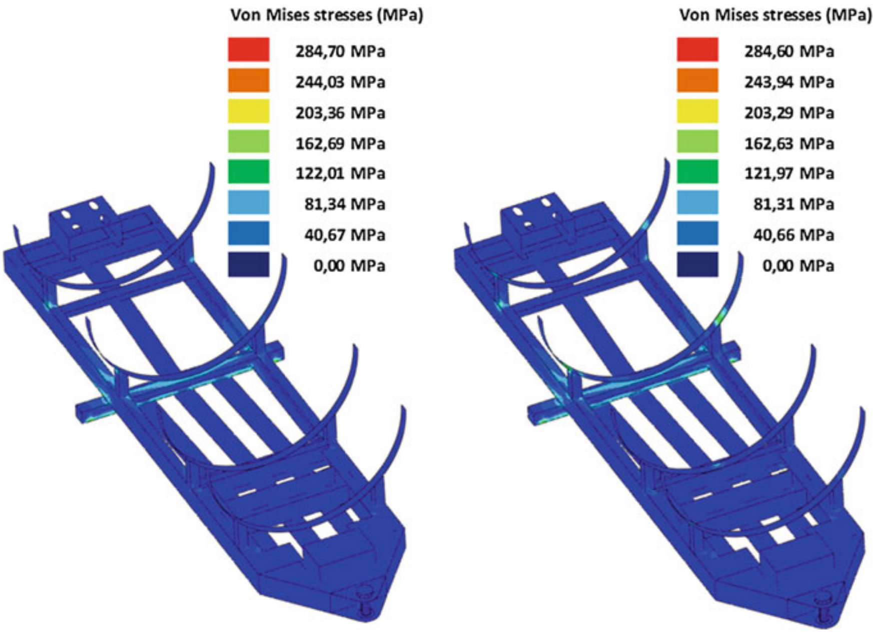

Fig. 13 Von Mises stresses obtained from the load case, 'lateral inclination' (*left*—initial design, *right*—optimized design)

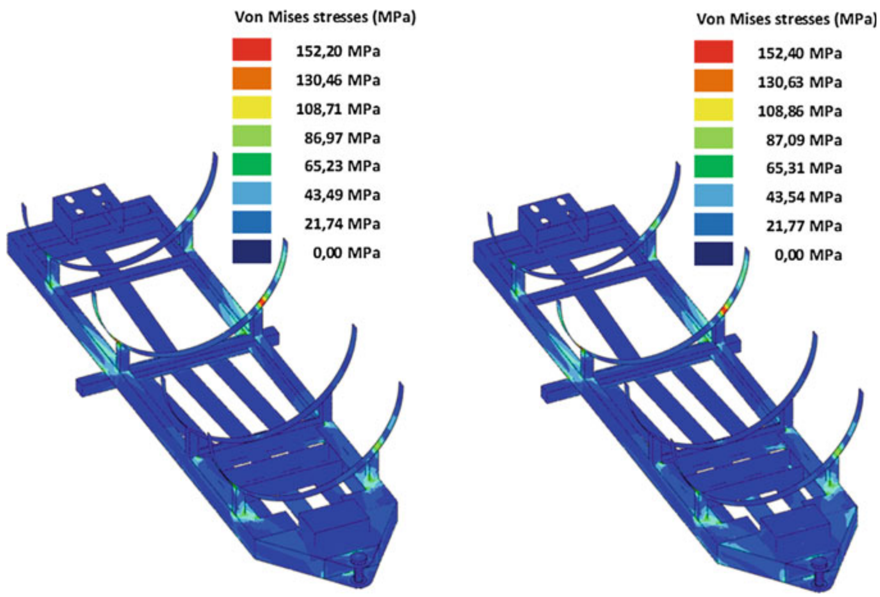

Fig. 14 Von Mises stresses obtained from the load case, 'swell' (*left*—initial design, *right*—optimized design)

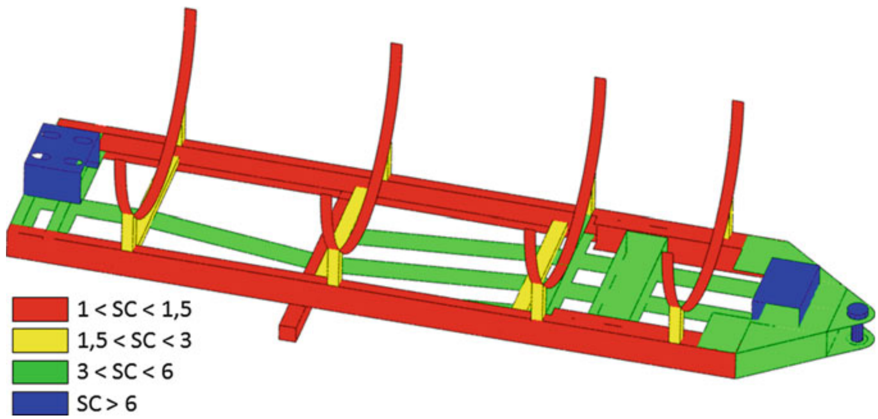

Fig. 15 Minimum safety coefficient of the optimized chassis components

Numerical techniques based on FEM were used in the analysis and optimization process. These techniques calculated Von Mises stresses and displacements, which allowed optimization of the chassis according to the resistance and stiffness criteria.

In this study, six load cases were analysed corresponding to 'chassis at rest', and the five most critical load cases from the point of view of the structural resistance of the chassis for the air-assisted sprayer: ‘initial impulse’, ‘inclination +5°’, ‘inclination −5°’, ‘lateral inclination’, and ‘swell’.

The optimized chassis design had no problems as per the resistance and stiffness criteria, and it reduced the mass by 18.50 % with respect to the initial model.

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Conceptual Design of a Small Electrical Appliance with Multiple Uses Following the Design-to-Last Approach

M. Royo, M. Navarro and E. Mulet

Abstract Nowadays a large variety of small electrical appliances are available to perform many functions and most of them are intended for tasks usually done in the kitchen. Different electrical appliances often have the same or a very similar main function such as heating a fluid (coffee-maker or tea-maker) or transferring heat to an object (bottle sterilizer or heater, food heater). Sometimes these products are designed for just one specific function, as in the bottle sterilizer or the heater, without considering how to apply them to other elements that could also be sterilized or heated. One of the design approaches that may guide the future of sustainable design is to design objects to last, thereby increasing their use. This work analyses the possibilities of integrating multiple uses to extend the life and use of a small electrical appliance, the main function of which is to heat, while proposing a conceptual design and assessing the improvement in its expected use.

Keywords Design to last · Multiples uses, modular design

1 Introduction

Today consumers have available to them a wide variety of products for many different functions that are continuously replaced or surpassed by new products that arise due to technology advances or to the emergence of new needs. However, there are few products which design takes into account the possibility of extending the

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life of the product by adapting it to new uses and technologies without disposing of the whole product.

The World Business Council for Sustainable Development (WBCSD) estimates that by 2050 the world's population will have reached 9200 million people, who would require 2.3 times more natural resources than the planet Earth has now available if they are to survive under similar consumption conditions to those of today.

Patterns of consumption and industrial production, among other things, are expected to bring about an increase in temperatures, which in turn would lead to large movements of population, a high ecological impact, and therefore a greater imbalance that would increase the gaps.

Under these circumstances, the WBCSD defends greater social, economic, environmental and quality of life balance, in forests, mobility, agriculture, buildings, economy and balance, that can, for example, take place in forest and human values.

In this sense, a change in how materials are used is proposed, which must be geared towards closing the circuit, doing more with less, not generating waste, using smart designs and integrating energy efficiency into the development of projects (WBCSD 2010).

One of the causes of the environmental problems affecting the world today is linked to the way in which society uses products. This can be seen by the tons of products with a large percentage of recyclable or reusable materials that are discarded (Pérez-Belis et al. 2012), the constant increase in the number of products demanded by a growing population or the reduction in the period of service of a product due to its low quality, the scarcity of options to update the product when a technological improvement appears on the market or when the user's needs change.

All this suggests that an important aspect of the product design in the near future will be to design objects that last longer than currently existing ones, that perform the same function or that are designed to extend their life, both through the design itself and its associated services (spare parts, upgrades, etc.). In this regard, the study by Lindahl and Sundin (2013) highlights both the need for and an interest in start-up business strategies such as the IPSO (Integrated Product and Services Offering) or PSS (Product/Service System), defined as "an offering that consists of a combination of products and services that, based on a life cycle perspective, have been integrated to fit targeted customer needs".

This leads manufacturers to assume greater responsibility in the use phase and to introduce products that are more efficient and durable. Accordingly, it will be increasingly more common for companies to include the future users' needs during the use phase within the design process, under a life cycle perspective, as a strategy to capture customers. This is a change from the traditional approach, in which the company's profits rely on the sale of a large number of articles—a model which, on the other hand, is weakened by increases in the price of raw materials and energy, the low labor costs from developing countries, and the increasing customer demand in developed countries.

Hence, in order to optimize how much the product will cost the customer throughout the life cycle, product design should achieve a functionality of the product that satisfies the client during a longer period of life, through the product itself and through its associated services. Modular design and service design play an important role in achieving this. However, there are several obstacles to their implementation, such as cultural barriers associated to consumer's habits. Also the difficulties for companies deriving from the complexity and uncertainty that results from a business model in which the services associated to the products take on more importance (Baines et al. 2007; Ceschin 2013).

An increasing number of studies promote a change in manufacturing companies to strategies in which services are more relevant than the products themselves (Iriarte et al. 2013). Other studies define methods to evaluate PSS in order to assist the decision-making among different alternatives, as in the aerospace industry (Bertoni et al. 2011).

This article focuses on products designed to reduce the use of materials and last for a longer time, for example, by using a modular design to update and adapt a product to the required uses without having to dispose of the parts that still work (Phoneblocks, Fig. 1a). Another example would be products that reduce the amount of materials required by customizing the purchase of a product so that it only

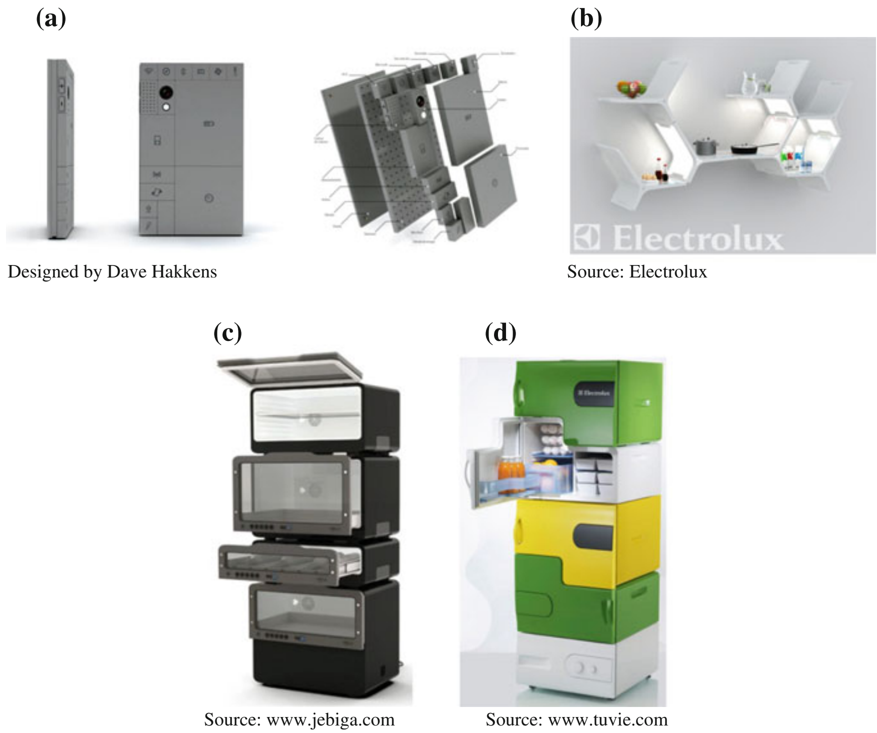

Fig. 1 Images of projects that adapt to the users' needs and lifestyle

includes the functions and parts that the user needs. This is the case of the innovative concept of the Electrolux kitchen, which consists of a number of modules that allow a high degree of adaptation to the user's demands, thereby, at the same time, adjusting the energy consumption (Fig. 1b). Another case is that of the Celsius (Fig. 1c) or Electrolux (Fig. 1d) fridges, which adapt to the changing needs of users over time.

The lack of incentives for companies, the interests that these practices generate, and the need to create a culture for a more responsible use of objects together result in a still scarce interest in designing products that minimize behavior based on "using and throwing away".

2 Objective

The aim of this article is to show how to increase the use of a product by integrating products within it that are usually presented separately. By doing so, its service life is extended, thus making it possible to adapt to changing needs through the use of materials and modularity.

3 Methodology and Case Study

The design process will be followed to design products that combine several functions in order to increase their useful life. In particular, the objective of this article is to integrate products that are typically used for limited periods of time or only sporadically so as to combine them with others that are used more frequently. First of all, the design problem is analyzed and creative techniques are applied to generate new solutions and finally the one which best fulfills the design objectives is selected.

The products chosen to be integrated into a more everyday use are the baby bottle warmers, which are used for very limited periods (Fig. 2a), and the electric

Fig. 2 Different designs for daily use. **a** Baby bottle heater (Photo credit Stephen Cummings). **b** Electric pood warmer (CC license). **c** Coffee machine (CC licence)

food warmer (Fig. 2b). Their characteristics and functionality are therefore analyzed in order to improve the usage of these products.

Once identified, these characteristics are integrated within the design of a new product, in this case, a coffee machine (Fig. 2c), which has a more continuous and frequent usage and its useful life is mainly conditioned by the speed at which technology advances. The objective is to obtain a new design with more functions and which, through modularity, allows all the damaged or technologically outdated components to be updated so that the original product can be used for a longer period of time.

To achieve this, a coffee machine is disassembled and its parts analyzed so as to know the architecture of the product and how to structure it in a modular way. Figure 3 shows the different components to be kept in mind when setting up the modules. Accordingly, the following modules are identified: housing module (Fig. 3a), head capsule module (Fig. 3b), water pump module (Fig. 3c), heater module (Fig. 3d), electrical circuit module (Fig. 3e), and finally the deposit module (Fig. 3f).

From the analysis of this product, possible conceptual solutions are explored for a new modular design that allows the user to expand, extract, and combine the parts easily. This will make it easier for the end-user to exchange the components, should they need to be repaired, updated or if the user wants to expand its functions.

As a final result a mock-up and a virtual prototype were developed to show the design proposed and to analyze the fulfillment of the objectives (Fig. 4).

The conceptual design that was developed integrates a product with a decreasing frequency of use that is needed over a very limited period, that is, a baby bottle heater, with a meal heater, which is used intermittently for a longer period, i.e., once or twice per day and person. These are in turn combined with another device with a

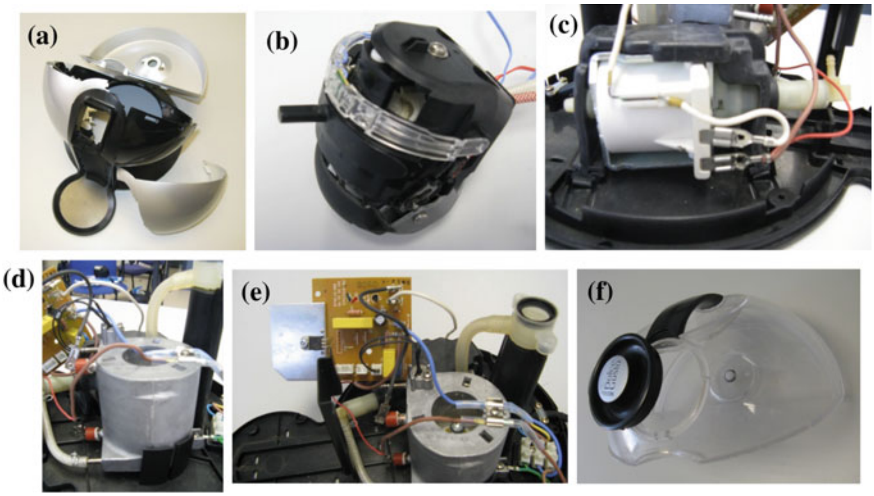

Fig. 3 Product architecture analysis. **a** Housing module. **b** Head capsule module. **c** Water pump module. **d** Heater module. **e** Electric circuit module. **f** Deposit module

Fig. 4 Mock-up of the conceptual design. **a** Four deposits combination. **b** Ten deposits combinations

high frequency of use, namely about three to four times a day per person for continuous periods of time, that is to say, the capsule coffee machine. The set is completed with a water tank, which can be extended according to the user's needs to supply both the coffee-maker and the heater. As seen in Fig. 5, the number of deposits can be duplicated depending on the frequency of use of the coffee machine in order to avoid the need for continuous refilling. The combination shown in Fig. 5a has four deposits and the one in Fig. 5b has ten.

Figure 6b shows the arrangement of the modules in the product, obtained following the modular design technique by Otto and Wood (2001). First, the functional analysis is performed and a transparent box is depicted to analyze the relationships among the functions to be integrated, as shown in Fig. 6a.

The product shown in Fig. 6b consists of a base, colored light brown (1), which contains a water pump and connects to the water deposit identified as (7). The

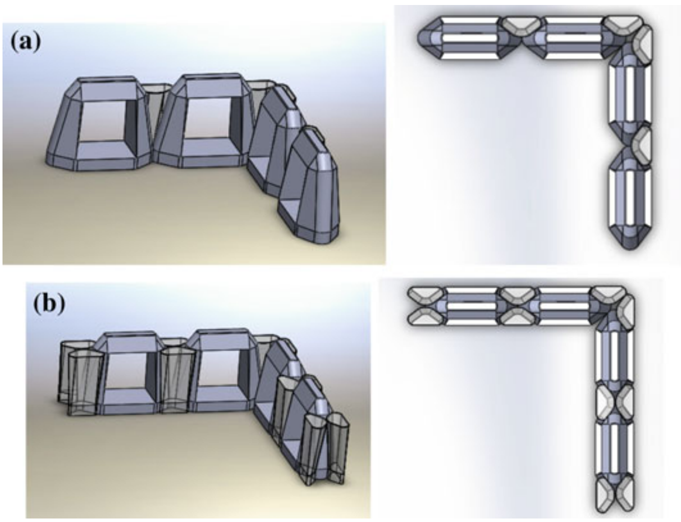

Fig. 5 Combinations according to the needs of the deposit module. **a** Four deposits combination. **b** Ten deposits combination

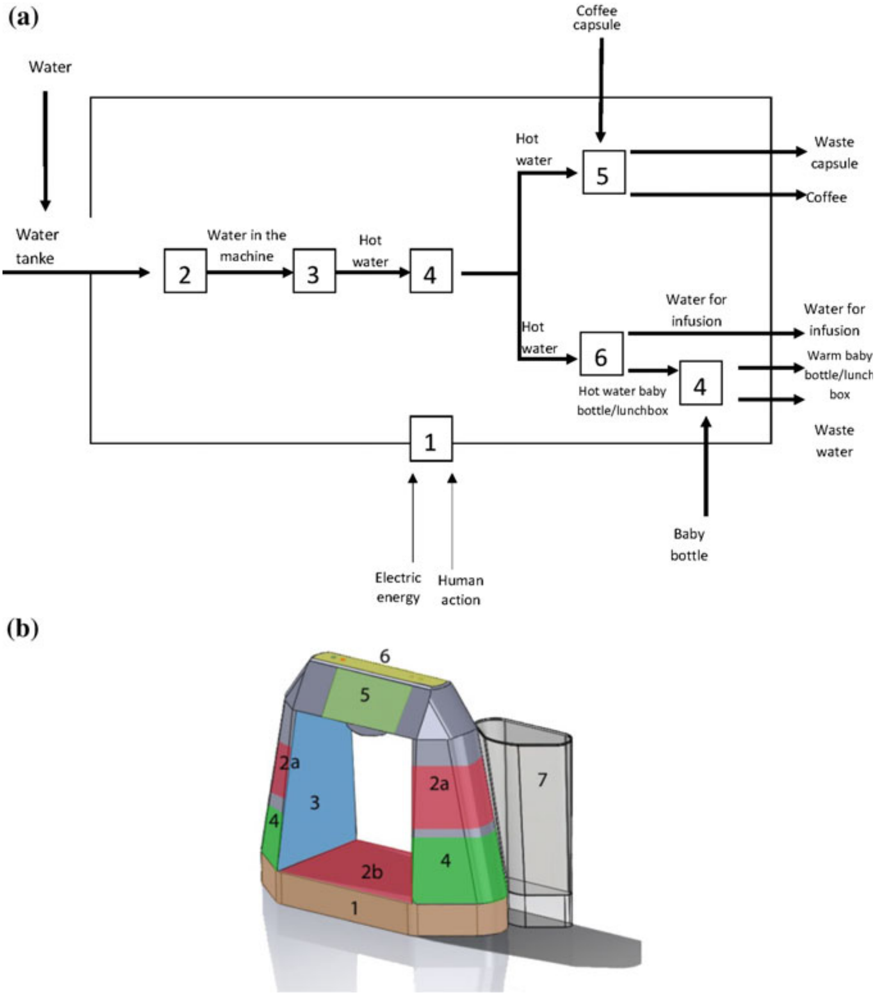

Fig. 6 Transparent box and arrangement of the modules in the product. **a** Functional analysis transparent box. **b** Arrangement of the modules

vertical connectors are supported through an internal wire structure which also contains the remaining modules. These connectors also allow for the assembly of the external housings that enclose the whole.

The vertical connectors support the heater module, colored red, which is composed of two parts: 2a and 2b. The red area marked as 2a corresponds to the electrical heating elements placed on both sides and it heats both the water for the coffee and the elastic area (3) located on both sides, which is made of flexible plastic bags that are filled with water to increase the volume in order to wrap the product (meal) to be warmed, which is located in the center. These flexible elements, together with the plate (2b), accomplish the effective warming of any product regardless of its form.

The green area (4) are pumps that drive water into the plastic bags (3) and to the top part of the structure (5), colored yellow, which contains the capsule coffee-maker mechanism.

Finally, the set has a yellow display (6), which contains the electrical components to control the temperature and the on/off switch of the device.

This arrangement ensures that the design meets the planned features to be a baby bottle heater, a food heater, and a capsule coffee machine.

Figure 7 shows how the product functions as a food warmer: the element to be heated is located in the central part of the product, on the heating plate. The user then selects the function, the temperature and the time on the display at the top, and fills the lateral water tank. After that the water in the tank goes to zone 1 (Fig. 6b), where it is heated and then goes to the pump (4), where it is driven to the flexible bags made of polymeric material (3), which are filled with hot water. These bags increase their volume and adapt to the element to which the heat is being transmitted by contact. Figure 7 shows the adaptation of the flexible bags with hot water to different containers, in this case, a bottle and a lunchbox.

Figure 8 shows the use of the product as a capsule coffee machine. At the surface of zone 1 the heated plate (2b in Fig. 6) remains heated on the surface of zone 1, where the coffee cup stands on. The user fills the water tank as shown in Fig. 8, and then switches on the device and selects the coffee-maker option on the display. This makes water run from the tank to zone 1, warm it up and go through the pump (4). Then the water is heated again in area 2a and reaches the capsule head (5), where the user has previously placed the desired coffee capsule. The system then pierces the capsule so that the ground coffee mixes with the water. The resulting coffee falls into the previously positioned container.

A few controls at the top of the vertical connector allow the user to select different programs and temperatures regardless of whether he or she uses the coffee machine in one side or the other, as it can be seen in Fig. 8.

The advantage of this product is its modularity and the ability to disassemble these modules to repair or to update them when the technology is outdated, without

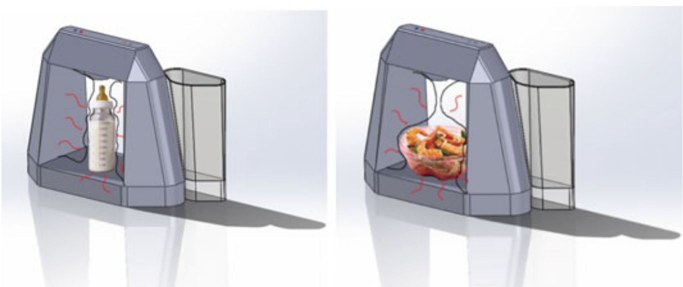

Fig. 7 Module used as baby bottle heater and as a food warmer

Fig. 8 Module used as a capsule coffee machine

the need to dispose of the whole device. For example, if the heating module (2a) is damaged, the user can easily remove the covers, access this module, extract it, and take it to a repair service. In contrast, if the coffee capsules technology eventually becomes outdated, the user can extract module 5 directly, and replace it with another one supplied by the manufacturer that will allow the continuity of the product.

Figure 9 shows different combinations of the product, which can be used individually or combined in different configurations.

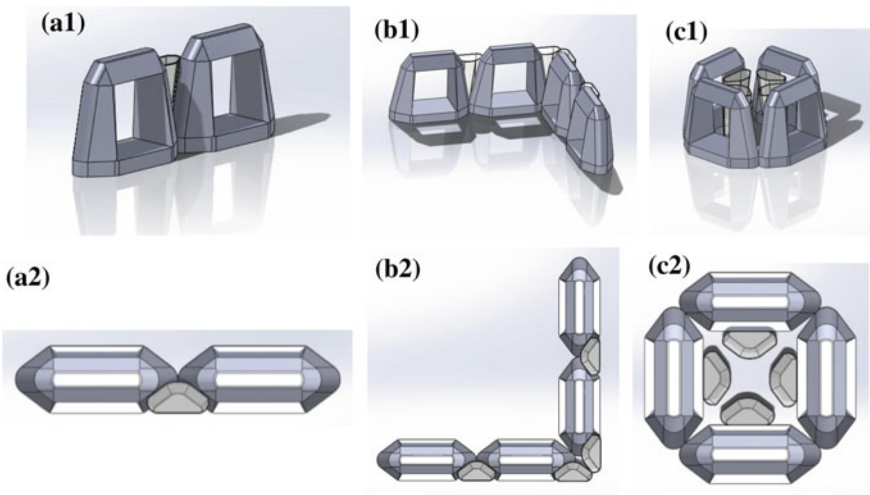

Fig. 9 Virtual prototype and its different combinations. **a** Linear combination. **b** Corner area. **c** Circular area

For example, joining two modules that will run independently as a coffee machine or water heater, with a tank that is shared between them (Fig. 9a1, a2), which can also be configured to fit a corner area (Fig. 9b1, b2) or as a circular island (Fig. 9c1, c2). The product can be integrated into any environment since the housings are interchangeable.

4 Results

The paper describes a conceptual design that integrates functions that are usually presented in different products, in this case, a product with limited use, as is the baby bottle heater, with a capsule coffee machine, which is used for a longer period of time but is subject to technology changes. The following step is to compare this design (P3) that integrates several functions, is modular and easy to disassemble, with a capsule coffee machine (P1) and a baby bottle heater (P2). This comparison comprises the three functions considered: making coffee, heating bottles, and heating lunchboxes. For each function the duration of use over time is represented on a horizontal axis, and the frequency of use is represented on the vertical axis. The horizontal axis also shows different usage scenarios—a total of four—which represent needs that may change over time (Fig. 10).

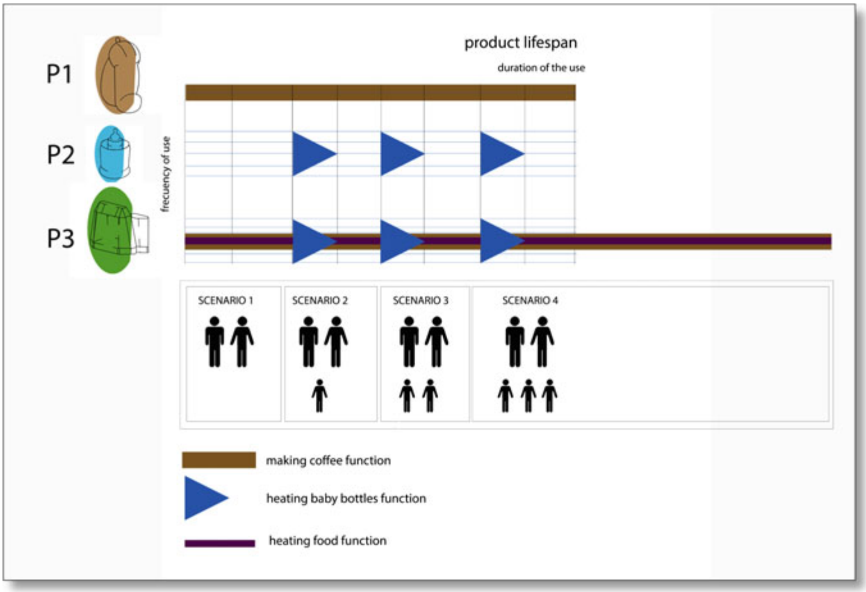

Fig. 10 Comparison of products

In the first scenario, the needs of two adults are studied, analyzing the expected usage over a period of time. The coffee-maker has a continued use of medium frequency and the bottle heater is not considered in this scenario. The proposed design is used more frequently, since the function of heating food once or twice a day is added.

The second scenario exemplifies the couple that now has a first child. The coffee-maker function continues and now the baby bottle heater is also used, more frequently at first and less frequently later on. The usage of the proposed design increases again now that the bottle heater is demanded, and goes back to the usage depicted in scenario 1 when the bottle heater is no longer needed for the first child.

In the third and fourth scenarios, the couple has a second and a third child and thus the baby bottle heater (P2) is used again during short periods of time. Once more, with the new design (P3) the use increases to perform the bottle heater function and finally it is used only as a coffee machine and food warmer.

In comparison to the baby bottle heater, integrating several functions as in the proposed design leads to a continued usage all the time, and the difference is that for particular periods of time it is used more because short-term functions are demanded.

Another difference is that at the end of the fourth scenario the first two products, i.e., the bottle heater and the capsule coffee machine, are no longer useful because the product is no longer required or it becomes outdated. With the concept developed in this study, even though the baby-bottle heater is not needed, the other functions are maintained over time since it allows its components to be updated easily as called for by technology changes.

It can be concluded that a new concept has been obtained which increases the span life of the product, since it adapts to the needs of users over time and it facilitates the repair and upgrade of its modules. This leads to a longer usage of the raw materials, and thus a slowing-down of the consumption of new materials.

Finally, the modularity of the product makes it easy to combine, so it is an outstanding product for use by communities such as cafeterias, social centers, universities, etc., in which each user can have different needs that the product can cater for. Above all, the food warming and baby bottle functions are especially interesting in public or private centers, since they allow parents to heat food for their children without external assistance and in a natural way—a service that can be difficult to find (Fig. 11).

Fig. 11 Concept settings

Moreover, the product can be integrated into any environment since the housings are interchangeable.

5 Conclusions

The findings are:

- A conceptual design of a product that increases both its usage and its lifespan has been proposed.
- A graphical comparison of the service life, frequency of use, and functions to be performed by different products has been established, including the concept developed, and the increase in use over time and its adaptation to the changing needs of users. The graphical comparison considers different use scenarios, each of which with its own needs.
- Different product functionalities have been integrated by means of a modular design, which allows damaged components to be replaced or updated.
- This work contributes to make headway toward the creation of a set of guidelines for the generation of new products that take into account the philosophy of material efficiency during the use phase.

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A Cost Analysis of Electric Vehicle Batteries Second Life Businesses

Lluc Canals Casals, Beatriz Amante García and Maria Margarita González Benítez

Abstract In the following years thousands of electric cars are expected to be sold. Knowing that their batteries cannot be used for traction services after they have lost a 20 % of its capacity, there will be thousands of batteries available for re-use. The re-use represents a considerable environmental improvement compared to the immediate recycling. According to battery recycling enterprises, not even half of them are collected back after being used and car manufacturers should ensure that their electric vehicle batteries will be correctly processed. A second life added value might help for a better deposition and management control. Although interesting, the second life re-use is not simple. Vehicles should first arrive to the dispersed authorized processing centers in the country. Once there, batteries should be extracted, packed according to legal regulations and transported to the restoration plant, where they will be tested, their components revised and they will be prepared for the second life application. All this implies personnel, transport, installation amortization and spare part costs. This work will present how appropriate the idea of the battery recovery for second life applications is.

Keywords Second-life · Reuse · Battery · Lithium · Electric vehicle

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1 Introduction

The Electric car is presented as a possible future solution to reduce the CO_2 emissions from the transportation sector. Government's efforts to reduce CO_2 emissions on the transportation sector, are a key factor to accelerate or retain the Electric Vehicles (EV hereinafter) entrance into the automotive market. Anyhow, even in the less optimistic case, thousands of EVs are expected to be sold during the following years (Anable et al. 2012). In fact, in the Spanish market (Fig. 1), the number of EVs registered in 2013 doubled the quantity from 2012 and it surpassed the 1.000 cars for the first time. It should be noticed that two car manufacturers (Nissan also Renault) cover more than the 80 % of the EV market.

The EVs are actually powered by batteries, most of them based on lithium technologies (Scrosati and Garche 2010). As Inevitably, batteries get degraded with its use (Broussely et al. 2005). For traction, it is considered that they are not appropriate anymore when they have lost between 20 and 30 % of their capacity or power capacity. At this point they should be removed from the car and, normally, collected for recycling.

European directives try to force batteries and accumulators waste collection. They do so by putting some pressure on battery manufacturers, charging them the costs of recollection (Directive 2006/66/EC) and setting collection targets of at least a 45 % of the sold batteries by 2016. Although intended, this does not usually happens for the small batteries on the market and, in fact, this target seems hard to achieve because of the inefficient battery and waste electrical and electronic equipment collection battery, electrical waste and because, in many cases, batteries are fully integrated in some appliances (Weyhe 2013).

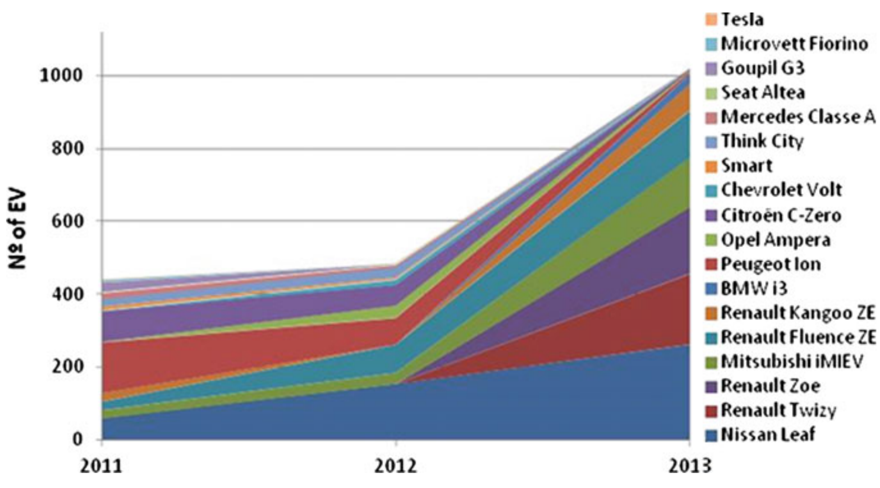

Fig. 1 Evolution of EV registered in the last years in Spain. *Source* Asociación Nacional de Importadores de Automóviles, Camiones, Autobuses y Motocicletas (ANIACAM)

Anyhow, EV batteries don't follow the same directive and the retrieval and recycling responsibility falls on car manufacturers. For them, up to 85 % of the car weight should be recycled and another 10 % can be energetically recovered. Therefore, it is important not to lose any of the EV batteries after its life in a vehicle, even if recycling batteries costs, nowadays, hundreds of Euros (Lithorec 2012).

There is one alternative to recycle though. Even if the used EV batteries are not performing as well the brand new ones, they are still in quite good condition compared to the average energy storage systems used on stationary applications. Therefore, some economic and use value might still be extracted from them with second uses before recycling.

From this point of view, second life's added value might help to improve deposition and control because the owner of the battery has something to gain. This is, indeed, not the only positive result: Second life might also lower the EV prices and make them slightly more attractive against the internal combustion (IC) vehicle. It may not make a decisive difference, but everything is welcome from the cost-reduction side (Canals et al. 2014). Still into economics, re-using batteries might evolve into lower battery prices for stationary grid applications and, hence, the implementation of micro-grids and decentralized energy production as well as the definitive integration of smart-grids and their supposed benefits within (Roberts and Sandberg 2011; Eyer and Corey 2010). And finally, a direct environmental impact reduction is derived from the use of second life's EV batteries (Ciccioni et al. 2012). If re-use finally exists, fewer new batteries should be manufactured.

All these encouraging aspects brought the idea of re-using the EV batteries for Battery to Grid (B2G) applications. In fact, the first economical approaches have been presented, although they used inaccurate life-length assumptions (Ciccioni et al. 2012; Sovacool and Hirsh 2009).

Even though interesting, the second life re-use is not a plug-and-play story. Batteries should be collected, revised, tested and arranged if necessary. Then, regarding its state of health (SOH), they should be classified and stored until the second-life installation is prepared. All this effort put into the batteries should be translated into costs. The subtraction of these costs to the 2nd life application's incomes and profit will resolve the "willing to pay" value for these used batteries. If these values are high, all the positive aspects will go on, but if it is too low or negative there will be not much hope.

This work will present the estimated costs for rehabilitation of EV used batteries. This is the first step needed to continue with the second-life's debate.

2 Methodology

This paper will begin with a brief analysis of the battery circuits during its first use in vehicles and their collection for re-use or recycle. The retrieval costs will be estimated from received offers by battery management integrated systems.

There are three main types of electric cars: Hybrid (HEV), Plug-in Hybrid (PHEV) and full electric (EV). Second life makes sense with big battery packs; therefore, the study will only consider batteries from PHEV and EV.

For these batteries, there are two main strategies to approach or address reuse. The first one consists in inreusing the batteries without much intervention. That is, trying to re-use the batteries in the same configuration as they are used in the car: same shape, same refrigeration systems, same covers… as if it were a black box (Carranza 2013). The second one opts to dismantle the battery in modules or cells and re-arrange them in a better configuration for the second use (Cready et al. 2003). Some of their main characteristics are presented in Table 1. In this work, both strategies will be analyzed.

A cost analysis is presented based on retrieval costs, functional and health tests, reuse plant investments, amortization and production time costs. Knowing that nowadays, and in at least the next ten years ago, the amount of batteries available will still be low, two approaches are studied: one for a reuse plant processing plant using 176 batteries per year, where workers are far from being saturated and they have great amounts of spare time; and another one planning on having enough batteries to support a factory with an optimized productivity. That is:

- For the direct re-use strategy: 6 test benches working simultaneously providing a total of 1056 batteries per year for both PHEV and EV with one worker per turn.
- For the module reconfiguration: two workers per turn to run 3 test benches for 528 PHEV re-purposed batteries annually and 2 test benches to work on 352 EV batteries.

For this work, the reuse plant will be located near one of the most important car manufacture centers in Spain, close to the city of Barcelona. Although theoretically this reuse plant could take batteries from all EV manufacturers, it was decided to work only with one battery type with only one battery type. It has to be taken into account that there is a huge diversity of batteries and that there is an important

Table 1 Comparison of the two basic reuse strategies

Direct re-use		Module reconfiguration	
Pros	Cons	Pros	Cons
Faster battery check	Rigid final product not suitable for all 2nd life applications	Optimized final product for specific 2nd life application	Much more preparation time
Easier rehabilitation process	Big battery manipulation	Manipulation of manageable modules	Need to build the new configuration
Re-use of all components	Need of additional interfaces for communication	Adapted BMS and refrigeration system	Design and programming of new components
Cheaper	Stackable at battery level	Stackable at module level	More expensive

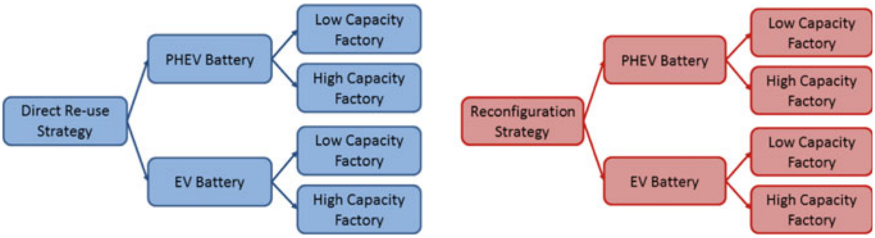

Fig. 2 Summary of the studied alternatives

amount of confidential information contained in a battery pack. In addition, the responsibility of these batteries throughout its life-cycle will fall under the car manufacturers. Therefore, car manufacturers will surely work hand-to-hand with only one company, like it is the case of the (4r-energy 2014) venture.

All the analyzed alternatives are summarized in Fig. 2.

3 Discussion

Cars are manufactured mostly in one production plant in Europe and then, distributed all around the territory or even abroad and overseas to car dealerships. Ideally, the battery collection route would bring the batteries of the distributed cars back to where they were produced (Fig. 3). In the EU and in Spain in particular, after the end of its life-cycle, cars should be disposed at the CATs for dismantling. They can arrive there by different means:

- The owner leaves the car at the dealership where he will buy a new one. Then, the car dealers should send the car to the CAT for dismantling.
- The owner brings the car directly to the CAT.
- There are municipal services that pick-up abandoned cars.

Fig. 3 Car selling and batteries collection opposed paths. Own source

Table 2 Car dealerships distribution in five cities for different car manufacturers

Barcelona	Sevilla	Bilbao	Madrid	Santiago de C.	Car manufacturer
39	10	10	43	13	SEAT (C. SEAT 2014)
21	9	10	49	2	RENAULT (C. RENAULT 2014)
18	4	8	26	2	CITROËN (C. CITROEN 2014)
14	1	5	15	1	MAZDA (C. MAZDA 2014)

Government incentives in renewing the automotive vehicle fleet and the facilities given by car dealers, favor the first option (Plan Pive5 2014). In any case, all these related costs are not taken into account in the analysis because they do not differ from the actual situation of ICE cars, so there should be no extra cost. Anyhow, it serves to understand the starting locations for battery collection. From Table 2 it can be observed that different car brands follow similar selling strategies, concentrating their efforts in the same cities.

There are more than 1200 CATs spread all around Spain, most of them are located near the places where more cars are sold (DGT 2014).

Once there, the vehicles are dismantled and their batteries removed. These costs will not be taken into account in the calculations because it does not differ from the actual situation. This is the last common path from IC vehicles and therefore, the last non-specific cost attribution.

It will be considered that no battery statement will be done at the Treatment Authorized Centers (CAT) where cars are disposed at the end of their life-cycle. According to legislation, damaged batteries are considered hazardous products (Ministerio de Asuntos Exteriores y Cooperación 2013), so their transportation should be done in special conditions: They should be placed inside two containers and at least one of them must be sealed and fire-resistant, increasing the transportation costs. Hence, although batteries conditions will not be determined, only batteries from crashed cars will be considered as damaged batteries. In fact, these batteries, for safety reasons, won't be reused and their managements costs will be added to the final value. According to the Spanish Government (Ministerio de Interior 2013) and from interviews done on local CATs, the number of crashed cars arriving at their installations is lower than 10 %.

Then, batteries will be transported to the reuse plant (Fig. 3). As there are more treatment centers than registered EVs in Spain, it is highly improbable that one particular CAT receives more than one battery per month. Hence, it will be considered that each battery will be collected individually from the CATs when they eventually receive an EV and take the battery off.

Once batteries are at the factory, their condition should first be determined by using climate chambers and precise electronic equipment. Nowadays, these tests are neither fast nor simple (Schweiger et al. 2010; Zenati et al. 2012). In fact, the VDA initiative, formed by the vehicle manufactures, has defined in the "Test specification for li-ion battery systems" a capacity and power pulse tests that, if strictly followed (Table 3), take about 126.25 and 78.6 h respectively. These timings are too long for

Table 3 Capacity and power pulse tests description from VDA-Initiative (2007/03/05)

Capacity test	Power test
Standard Cycle	Acclimatization at 40 °C
Acclimatization at −25 °C	Standard cycle
Discharge 1C	Acclimatization at 40 °C
Charge at cell nominal (C/3 normally)	Discharge 1C until 80 % SOC
Wait 30 min (for temp. stabilization)	Acclimatization
Repeat 3 times Charge/discharge cycle	Pulse:
	Discharge at Imax for 18 s;
	Relaxation for 40 s;
	Charge at 0.75*Imax for 10 s
	Relaxation for 40 s
Acclimatization to RT	Discharge until next SOC step
Discharge 10C	Repeat for SOC 65, 50, 35, 20 %
Charge at cell nominal (C/3 normally)	Standard charge 1C
Wait 30 min (for temp. stabilization)	Acclimatization at RT °C
Repeat 3 times charge/discharge cycle	Standard cycle
Acclimatization to 40 °C	Repeat pulse test for all SOC steps
Discharge 20C	Acclimatization at 0 °C
Charge at cell nominal (C/3 normally)	Standard cycle
Wait 30 min (for temp. stabilization)	Repeat pulse test for all SOC steps
Repeat 3 times charge/discharge cycle	Acclimatization at −25 °C
Acclimatization to RT	Standard cycle
Standard charge	Repeat pulse test for all SOC steps

any business to run, therefore we will consider that a time improved test will be executed lasting no more than 24 h.

Depending on their performance results, the batteries will be classified according to the second life applications needs. Then, special arrangements and maintenance tasks will be take place, such as the implementation of communication interfaces to adapt the Battery Management System (BMS) strategies to the needs of second use applications or to change degraded materials. Finally, they will be checked again in order to validate its complete functionality. This final check won't be as demanding as the first one because it is not intended to search the battery SOH. It just checks if it will be able to execute the requested services. It should be noted that batteries coming from crashed cars will be immediately sent to recycle plants.

For the module reconfiguration strategy, batteries will be dismantled before the first functional check and then each module will be verified independently following the same procedures. Once checked and selected, the modules will be regrouped in categories to build a new battery pack completely different from the original car battery; it can be smaller or even bigger. The main difference is that in this case, the refrigeration systems and the BMS will be completely new, while in the previous case they will also be re-used.

Then, the reused batteries will be stored in a special warehouse, with all the safety systems required, waiting for its shipment to their new installation.

4 Results

In lithium batteries, Cobalt is the most valuable element to recycle. Therefore, recycling plants pay to receive the ones containing more than a 5% of its weight of Cobalt. As EV batteries have much less than this percentage of Cobalt, it is the manufacturer who has to pay for them to get recycled. Taking an average of different offers received, it has been calculated that the collection of a Plug-in Hybrid Electric Vehicles (PHEV) battery should cost around 170 € while EV ones will rise up to 316 €. Their packaging is considered to cost 20 and 38 € respectively.

The calculation of the re-manufacture plant, which takes into consideration investment, consumables and personnel costs, follows.

In order to have an approximation to the plant dimensions and costs it is important to know the production time and processes. In general, EV batteries are twice as big as the PHEV ones, then, the dismantling and module reconfiguration strategy using EV batteries needs more time than using the PHEV ones. This is not such a problem when running the Direct re-use strategy, as the battery is treated as a pack. In Table 4 a comparison is shown of the production time associated to each of the strategies followed and the size of the battery to be prepared. It can be appreciated that the time difference between both strategies is 10.5 and 20.9 h for

Table 4 Time distribution of direct re-use and module reconfiguration strategies

Direct re-use		Module reconfiguration		
Operation	PHEV & EV time (h)	Operation	PHEV time (h)	EV time (h)
Physical inspection	0.5	Physical inspection	0.5	0.5
		Battery dismounting in modules	5	9
Test preparations	1	Test preparations	2	3.6
Battery test	24	Battery test	24	24
Disconnection and battery classification	0.5	Disconnection and modules classification	1	1.8
Interface mounting and maintenance	1	Battery rehabilitation	5	9
Functional battery tests	0.5	Functional battery tests	0.5	0.5
Storage	0.25	Storage	0.25	0.25
Shipping	0.5	Shipping	0.5	0.5
Total	28.25	Total	38.75	49.15

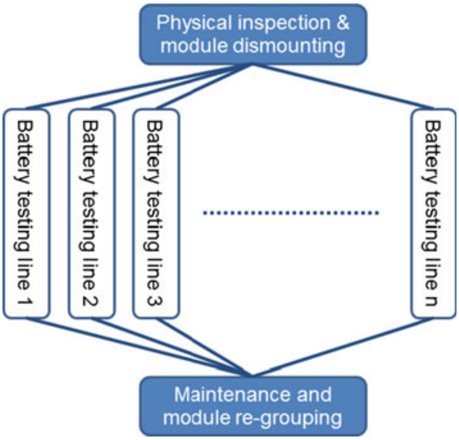

Fig. 4 Duplicity of battery test benches or lines schema

PHEV and EV batteries respectively. That is equivalent to say that means that the reconfiguration strategy needs 3.5 and 6 times more manipulation time than using the direct re-use strategy.

As presumed, a bottleneck is found in the battery test and test preparation operations. The duplicity of testing benches or lines would help to substantially reduce waiting times (Fig. 4). For the direct re-use strategy, starting with one worker doing both initial and last operations (Physical inspection and maintenance), up to 6 batteries could be tested simultaneously, having one battery ready every 4.7 h (n = 6).

On the other hand, for module reconfiguration, the time it takes to work on a battery is 14.75 h for PHEV or 25.15 h for EV. In this case, for an EV battery almost the same time is used almost the same amount of time is needed for battery preparation and testing preparing the battery and for testing it, meaning that workers are saturated. Then, if the battery benches are duplicated to provide time reductions, the dismounting and mounting operations should be done by different operators. If two workers are employed per turn, up to three lines could be installed for PHEV and two for EV batteries.

Many combinations can be analysed regarding these options but reality should not escape from our scope. Taking a look at the number of registered cars in Spain (Fig. 1) it can be appreciated that the bestselling model delivered just 270 cars (less than one car per day). That means that, in the next ten years, no more than that number of batteries will arrive yearly to the reuse factory. That is the reason why two approaches were chosen, one for the first steps, when there are not many batteries, and another one considering a high capacity reuse factory.

The economical results are shown in Fig. 5. It can be appreciated that at higher capacities, the costs of re-use batteries is reduced. It can also be noticed that direct re-use is always cheaper than re-worked batteries under similar productivity environment. The best prices are 122 €/kWh from PHEV batteries and 87 € from EV.

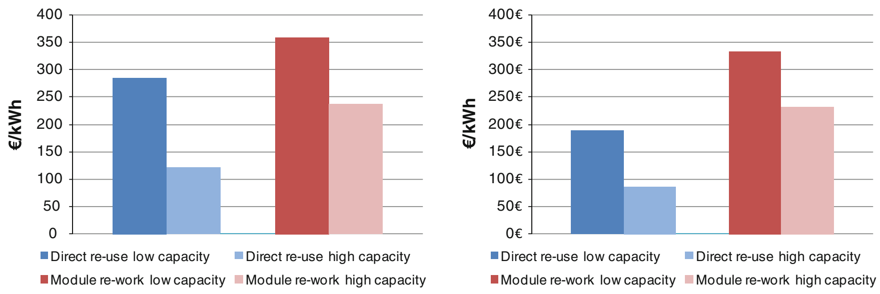

Fig. 5 *Left* Cost per kWh of a re-used PHEV. *Right* Costs from EV second life batteries

Packaging and maintenance have fixed costs, that is, these costs do not depend on the strategy followed. Hence, when examining in depth the cost distribution (Fig. 6), it is visible that their impact is greater in the high capacity options. It is also understandable that the module re-working strategy needs more materials to build a "new" battery, thus, higher costs and bigger impact. Of course, the production costs take the biggest part in all four studied cases, representing always more than 70 % of the total.

Finally, examining at the production costs (Fig. 7), it is evident that the impact of labor costs, investments amortizations and other costs (electricity, maintenance, etc.) also change with the strategy and productivity solution chosen. Obviously, labor costs are more important in low capacity solutions than in alternatives with more production capacity, where investments are needed. For example, direct re-use in a high capacity configuration, with up to six test lines in parallel, has an investment impact above the 50 % of the final production cost.

A list of installation requirements is presented in order to better understand the investments involved in second-life battery reconfiguration: Climate chambers,

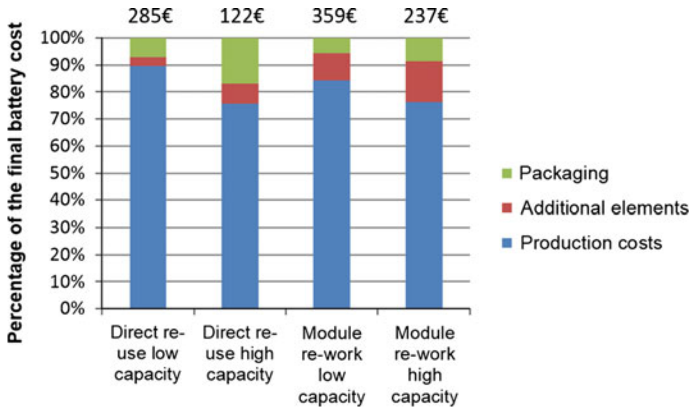

Fig. 6 PHEV battery total cost distribution

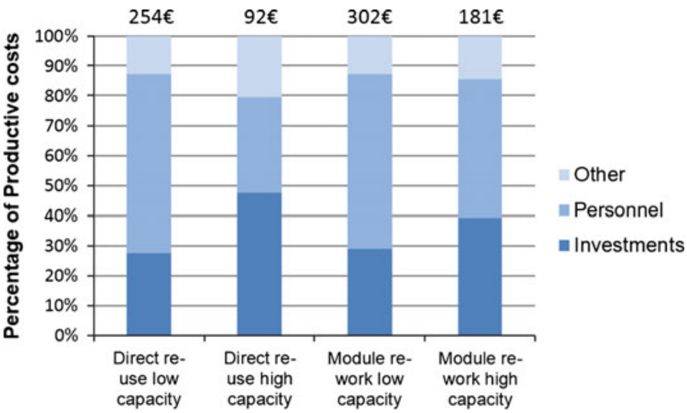

Fig. 7 Distribution of PHEV productive reuse costs for each solution

high power and energy testing equipment, prepared warehouses and storage racks, conveyors, forklifts, office equipment and industrial plant annual rent.

In the end, it is evident that the faster the production, the lower the prices are and the smaller the labor cost impact will be. It is also noticeable that the cost reductions are more visible in direct re-use.

5 Conclusions

Nowadays, new batteries cost near 800 €/kWh and the expected prices for 2020 are around 400 €/kWh (Neubauer et al. 2012; Price et al. 2012).

The costs of reused batteries, independently of the strategy chosen, are always under 360 €/kWh. The best price obtained is 87 €/kWh from direct re-use of EV batteries on a high capacity factory. Indeed, it is 4 times cheaper than a low capacity re-worked one.

If if more than 500 batteries are received per year, it is highly probable that the business will be profitable. A brand new battery will cost four times more than a reused battery with the best price resulting from this study. That represents a substantial potential for second-use batteries to have a niche in the energy storage market.

Anyhow, It can be concluded that the module reconfiguration strategy will not be very attractive in the beginning, at least at the beginning, because there's not enough margin between the re-purposed cost and the expected price from new batteries. In fact, the direct re-use solution clearly takes the lead.

It can also be stated that EV batteries provide better economic results than PHEV ones because they have more modules, thus, capacity in relation to the time invested in the process.

This study shows that as the number of EV batteries available increases, the results are better. Even the most intensive solution presented involves a great amount of manual work. Industrialization can easily provide lower costs if there are enough re-manufactured batteries to invest in.

Another expected improvement will surely come with a more efficient battery SOH assessment test, which is something car manufacturers are already working on. Actually, car manufacturers are also working on the development of a BMS prepared for first and second uses which will facilitate their integration in the net.

From the obtained results, It can be suggested that re-used batteries will speed up the entrance of storage systems into grid ancillary services.

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Work Procedure for Evaluating Conceptual Users' Experiences Using the Multimethod Tool EyeFace

Ganix Lasa, Daniel Justel and Aiur Retegi

Abstract The assessment tools used in development processes must meet specific conditions to guarantee their successful application in business. Defining a work procedure for the multimethod tool EyeFace will help to meet these conditions and integrate this new tool into an experience design process. The aim of this paper is to define a specific work procedure for the new multimethod assessment tool EyeFace and to evaluate users' experiences of it at a conceptual level. To achieve this aim, an experiment was carried out to evaluate users' experiences with Fundawear, a new product created by Durex.

Keywords Eyeface · Experience evaluation · Conceptual phase · Eye-tracking · Facereader

1 Introduction

An increasing number of companies are adding experience design to their innovation processes. These new experience design processes have provided many companies with a way to participate in the new Experience Economy paradigm (Pine and Gilmore 1998). However, the development of new experience design methodologies has made it necessary to establish specific measures for evaluation.

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In recent years, many different methods have been created to assess users' experiences, and there are databases that collect many of the methods that have been created so far, such as those by Engage (2006) and Humaine (2008).

Despite the creation of new tools and methods, companies are not adding them into their existing processes. Thus, Väänänen-Vainio-Mattila et al. (2008) detected a significant gap between academic research and companies' realities. On the one hand, academic research defines frameworks and focuses on theoretical aspects of users' experiences in design models. Apart from hedonic and emotional approaches, different aspects like co-experience and dynamic experience are also taken into account. On the other hand, some companies take a much more practical experience design approach where the aim is to support product development to ensure its success in the market. The main features in this area include functionality, usability, innovation and product lifecycle.

To close the gap between the two areas of academia and business, Väänänen-Vainio-Mattila et al. (2008) created a detailed framework to encourage companies to use experience design methods. The authors defined nine requirements for integrating experience based evaluation methods in business processes. These methods must be

1. Valid, secure and repetitive.
2. Fast, light and cost efficient.
3. Applicable with low specific knowledge.
4. Suitable for different types of products.
5. Applicable to conceptual ideas, prototypes and final products.
6. Suitable for different user groups.
7. Applicable at any point of product lifecycle.
8. Capable of providing comparable data (i.e. quantitative and qualitative).
9. Useful for different agents and business departments.

Partial or full compliance with these requirements will assist in the following: properly using these tools within the design process, evaluating the new products and services and ensuring the application of these products and services in companies.

This paper aims to establish a working procedure for the new experience based evaluation tool named EyeFace (Lasa 2013). We want to develop an appropriate work procedure for the experience based evaluation, properly implement the tool in the concept creation process and facilitate the use of this new evaluation tool in the business process.

To propose and validate a specific work procedure, this research has performed an experience evaluation of the Fundawear product created by Durex (2013) using EyeFace as a tool.

2 Objective and Hypotheses

To enhance the implementation of new experience based evaluation tools within design processes, this paper aims to validate the work procedure for EyeFace using the requirements defined by Väänänen-Vainio-Mattila et al. (2008) and to evaluate its integration within an experience design process.

To achieve this, the research will establish a working procedure for the experience assessment tool EyeFace. First, EyeFace-related procedures like Eye-tracking and FaceReader will be reviewed. Then, we will carry out a case study to validate the experience-based work procedure. Finally, the results of the study will be analysed and conclusions will be drawn that will be helpful in conducting future work.

3 EyeFace: A Multimethod Tool

The multimethod tool EyeFace (Lasa 2013) works with two different devices: Eye-tracking and FaceReader.

Eye-tracking equipment identifies users' gazes while they perform a specific operation, and it stores the data for analysis. Eye-tracking is composed of two video recording cameras and requires specific software: the Smart Eye Pro 5.5 and Gaze Tracker 8.0.

FaceReader analyses the emotional reactions of a user in a specific period of time, and the graphic information collected through the camera is decoded into a specific emotion. This system consists of a webcam and FaceReader 2.0 software.

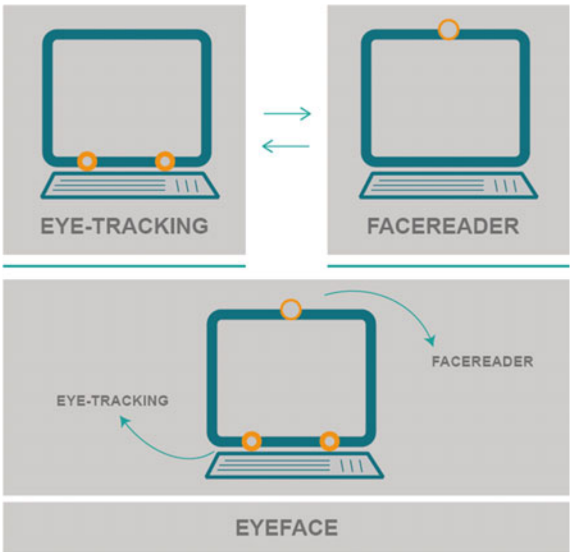

Fig. 1 EyeFace illustration

EyeFace requires a computer to handle each tool: Eye-tracking and FaceReader. To install EyeFace, FaceReader's webcam is installed alongside an Eye-tracking device. Thus, user analysis is performed within a computer that contains Eye-tracking device (Fig. 1).

These two devices are mostly used separately to evaluate websites and digital platforms. By combining these two tools, EyeFace may be used for product and services that are related to experience-based evaluations in the conceptual phase of the design process.

4 Other Interactions and Perceptions that Are Related to Work Procedures

The work procedure proposed by software creators for Eye-tracking and FaceReader was not suitable for performing experiments due to EyeFace's specific characteristics. Although EyeFace software guidebooks (Smart Eye Pro 5.5 2009; Gaze Tracker 8.0 2008; FaceReader 2.0 2008) do not define a work procedure, the structure of usage can be identified: (i) System configuration, (ii) Device calibration, (iii) Conducting the experiment and (iv) Analysis of the results.

Meanwhile, the ISO 9241-151: (2008) standard for the certification of product usability proposed a similar work procedure for the identified structure. The ISO 9241-151 standard defined the framework for human-systems interaction ergonomics, which is outside the specific scope of EyeFace. However, it is also related to experiences and could be useful as a reference when defining a work procedure. The five steps defined by the ISO are as follows: (i) Preparation and sampling (ii) Conducting the experiment, (iii) Analysis, (iv) Preparing a report and (v) Evaluation.

Aside from general work procedures, Goldberg and Helfman (2010) described three different strategies for the experiment analysis. They focused on the data analysis phase using the Eye-tracking device and the representation form: (i) Analyse the path lines and fixed points, (ii) Analyse the gaze over time and (iii) Analyse data using radial diagrams.

A more detailed framework is provided by Nielsen Norman Group—NNGroup (Pernice and Nielsen 2009) that defines the key elements for the proper execution of Eye-tracking experiments. Among other things, they highlight that the experiment must be carried out and supported by a facilitator to ensure that the activity is carried out properly and to avoid user doubts.

For the multimethod EyeFace tool, which combines two different tools to obtain user perception data, only certain strategies and representations are suitable. A proper experience evaluation work procedure should be carefully defined and take into account the defined requirements for business implementation.

5 Work Procedure for EyeFace

The proposed work procedure for EyeFace is based on a combination of the ISO 9241-151 and procedures proposed by device manufacturers. The following work procedure was defined to evaluate the experience of using EyeFace:

1. Identification and selection of users.
   - The development team will assess which type of user is most appropriate for evaluating concepts by specifying various aspects like age, gender, lifestyle and profession.
   - The number of users required for the analysis varies. Despite the amount of qualitative data obtained by EyeFace, at least five users must be analysed during the experiment.
   - The designer should estimate the duration of the experiment and outline the planning and timing of the study to determine the amount of resources required.
2. Carrying out the experiment—Introduction.
   - A facilitator will moderate the whole experiment. They will explain the content and describe the details of the experiment. The facilitator must know how to use EyeFace and must be able to manage users using specific strategies and techniques.
3. Device calibration.
   - EyeFace must be calibrated at the beginning of each study and with each participant.
4. Experience concept evaluations using EyeFace.
   - Depending on the complexity of the conceptual experience, the facilitator should describe the concept to avoid misunderstandings. At the end, the user must understand the experience in its entirety.
5. Questionnaire implementation.
   - The questionnaire will inquire about issues that will reveal users' overall perceptions about the displayed concept. This approach will be helpful in gaining valuable information from the user and in establishing selection criteria when choosing one concept in particular.
   - Three questions related to perception, acquisition and prior knowledge will be proposed:
     – Overall rating: from 1 to 10.
     – Would you buy it? Yes or No.
     – Did you know about the product before the experiment? Yes or No.

6. Results analysis.
   - The designer should be familiar with the data obtained by EyeFace to ensure its proper management and interpretation.
   - The data require a specific analysis strategy so that two devices may be analysed at the same time. The gaze trajectories lines and attachment points must be analysed (Goldberg and Helfman 2010). The graphs of users' emotional perceptions provided by FaceReader must also be analysed.

6 Implementation of the Procedure. Case Study: Concept Evaluation of Fundawear by Durex

The work procedure defined above will be applied in this case study, and the Fundawear concept will be assessed. Fundawear provides a product-related experience that aims to maintain desire and engagement between couples who are geographically separated.

Fundawear consists of two elements. First, it consists of underwear for men and women containing small stimulators that border some of the most sensitive areas of the body. Second, a mobile application allows for control and interaction with the other person's underwear. To promote this new concept, the company launched a video that is available on YouTube and shows the Fundawear experience (Durexaustralia 2013).

The video shows a video call where a couple is wearing and interacting with the Fundawear. They have a short conversation and then start using the product. The video allows for a better understanding of the product. It also conveys the emotions that the couple experienced during the video call. It presents a completely authentic scenario to be evaluated by potential users.

6.1 Identification and Selection of Users

Seven people (four males and three females) participated in this case study. Participants were residents of Spain, university students and between 22 and 33 years of age. This specific user profile includes potential Fundawear users in the near future (e.g. business trips, Erasmus). As such, these participants could easily imagine themselves experiencing the situation portrayed in the video and could relate to the experience particularly well.

6.2 Carrying Out the Experiment—Introduction

An evaluation of this case study was performed by a facilitator who was commissioned to make a brief introduction and to describe the context of the experiment to the participants.

6.3 Device Calibration

The devices must be calibrated to ensure the accuracy of the final results, so EyeFace was calibrated with each participant before the evaluation.

6.4 Experience Concept Evaluation Using EyeFace

The video about Fundawear was shown to the participants, and the facilitator did not stop the video in any of the cases. The participants did not require explanations of the proposed concepts.

6.5 Questionnaire

As indicated in the work procedure, after the concept was evaluated by EyeFace, participants answered a three-question questionnaire to better address users' overall perceptions:

- Overall rating: from 1 to 10.
- Would you buy it? Yes or No.
- Did you know about the product before the experiment? Yes or No.

6.6 Results Analysis

In this case study, the facilitator who carried out the experiment analysed the results of the EyeFace data and questionnaires.

Regarding EyeFace, collected data show that FaceReader has identified a behaviour pattern that must be carefully analysed. The device occasionally interprets emotional responses improperly, as shown over time in user three's emotional balance chart (Fig. 2). The device indicated a negative emotional balance, but the user was merely observing the concept in a neutral mood.

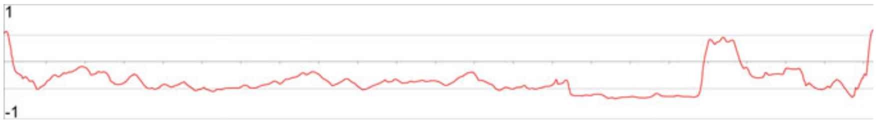

Fig. 2 Emotional balance for user three

In these cases, when the user's face is identified as not being neutral, the analysis should be limited to the identification of sudden changes in their emotional balance. Figure 3 shows one of these sudden emotional reactions for user three. The emotional balance goes from a negative value to a significantly higher value (1:30 min); therefore, it is identified as a key, interesting moment for analysis. Figures 3 and 4 show EyeFace data for a specific emotional reaction. It shows a key moment in the emotional chart and in the gaze trajectories at the same time.

Regarding the questionnaire, the overall average evaluation was 7.85 out of 10. Thus, it is understood that the proposed experience can generate positive emotions or feelings.

The questionnaire also shows that five out of the seven users would purchase the Fundawear. Paradoxically, the users who assessed the concept with the highest marks (9 out of 10) would not buy the product. Given that result, it would be

Fig. 3 Emotional balance details for user three

Fig. 4 Gaze trajectories for user three

interesting to analyse whether the results are related to specific feelings like shyness.

Finally, the results show that the vast majority of users did not know about Fundawear or a similar product. Thus, the surprise factor could be an interesting point for analysis; in this case, the novelty of the Fundawear or any new concept could increase users' positive perceptions and stimulate higher emotional reactions and overall evaluations.

7 Conclusions and Recommendations for Further Study

Experience design is a new discipline that is gradually gaining ground within industrial companies. However, it is still difficult for businesses to add new tools and approaches in their design processes.

In this regard, Väänänen-Vainio-Mattila, Roto and Hassenzahl (2008) defined a framework to introduce new methods in the industry. Their research validates that EyeFace meets all the set requirements, as explained below:

1. Valid, secure and repetitive: The software provides security and stability by using EyeFace. The analysed parameters enable the experiments to be repeated. The subjectivity of human perceptions and the evaluation of the experience itself remain critical components.
2. Fast, light and cost efficient: The tool is fast, can be used in a short period of time and produces data that are easy to analyse. Regarding costs, the devices are not currently expensive, and the price will drop over time. However, it would be interesting to develop a mobile EyeFace device to facilitate mobility and user analysis in different environments.
3. Applicable with low specific knowledge: The devices are intuitive, and the collected results are very easy for the designer to manage and understand (even if the designer is not an expert). Furthermore, the work procedure proposed in this paper will help in carrying out future experiments.
4. Suitable for different types of products: EyeFace can be used to analyse different kinds of products. In fact, there is a similar tool called Emoscopio (Bustillo 2007) that is used to evaluate the usability and interactivity of products, websites and mobile applications.
5. Applicable to conceptual ideas, prototypes and final products: In this research, the work has been evaluated as a conceptual idea. However, as long as prototypes and products are shown on a screen (i.e. using video or images), you can use EyeFace.
6. Suitable for different user groups: EyeFace is very flexible in this regard. All types of users can be analysed using this new tool. However, this version does require the experiments to be conducted in a lab. Thus, mobile, wireless or online resources are required to collect information from different environments.

7. Applicable at any point in the lifecycle: EyeFace allows for the evaluation of an experience at any point during product lifecycle using digital resources like photos, sketches or videos.
8. Capable of providing comparable data (quantitative and qualitative): The amount of data that can be collected using EyeFace is relevant to understand user perceptions and will be very useful in the design process.
9. Useful for different agents and business departments: EyeFace collects data from two different devices. The analysis of the results could be both interesting and useful for many other departments.

Beyond these requirements, this research has demonstrated that the proposed work procedure was satisfactory. However, as stated above, data collected from FaceReader must be carefully analysed; therefore, we propose that the focus be on sudden emotional reactions.

One interesting point for analysis is the questionnaire that was added to the work procedure. The questionnaire shows a gap between the overall product evaluation and the desire to purchase the product. Therefore, it would be interesting to gain a better understanding of users' motivations and general perceptions. To do so, it would be helpful to ask about the key moments of the experience and to focus on emotional balance, as previously suggested. Thus, the designer could collect valuable information to develop specific experiences.

Based on Beyer and Hotzblatt's (1997) research, we decided to add the third question, which asks whether or not participants had previously known about the product. However, the results did not allow us to reach an accurate conclusion. However, it would be interesting to analyse the influence of the surprise factor in the evaluation process in future work.

Similarly, we think that Duchowski's (2003) approach should be used in future research. The approach evaluates pre-experiment reflection to identify key moments of the experience, to guess at users' perceptual and interactive reactions and to promote thinking about potential user behaviour during the experiment. Thus, before the experiment, the designer could attempt to identify key moments that might affect users' emotional balance and reflect on potential user reactions.

To sum up, the new EyeFace tool allows us to evaluate conceptual experiences and fulfils all the requirements established by Väänänen-Vainio-Mattila et al. (2008). However, taking into account the complex reality of human perception, it could be interesting to add new tools and more detailed questionnaires when using EyeFace. Furthermore, the work procedure that has been defined in this case study is the first version and would be particularly helpful for inexperienced designers. However, certain changes over time should be assumed.

Based on this research, we propose a new working procedure for future EyeFace experiments:

1. Pre-experiment—Hypothesis.
2. Identification and selection of users.
3. Carrying out the experiment—Introduction.
4. Device calibration.

5. Experience concept evaluations using EyeFace.
6. Questionnaire distribution and completion.
7. Analysis of the results.

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Product Phenetics as an Alternative to Establish a Relationship Between Morphology and Perception Associated to Industrial Products

Miguel Ángel Artacho Ramírez, José Manuel Arrufat Álvarez and Enrique Alcántara Alcover

Abstract Morphological analysis can be a valid alternative in order to control the relationship between different design proposals and what these connote and denote. This work suggests a new perspective of perception analysis of products based on phenetics and cluster analysis. Ten drill models are digitized, morphologically compared and grouped depending of a proposed dissimilarity index based on the Procrustes Method. In the same way, the cognitive and emotional responses, and the purchase intention related to the power tools belonging to each of the groups are all obtained by using semantic differential method. As a result there appear statistically significant differences between the user's perceptions of the different morphological clusters. This way the methodology being followed in this work is justified and the proposed dissimilarity index is granted validity.

Keywords Design · Morphology · Clustering · Phenetics · Perception

1 Introduction

User-centered design has gained in importance during the last few decades (e.g. Kaulio 1997; Nagamachi 1999). Initially, this approach was mainly focused on functional product properties, but specialists became aware of the inadequacy of

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only controlling these properties to fulfill the requirements of users who have become more and more demanding (e.g. Mano and Oliver 1993). This was due to the growing importance of products physical appearance (e.g. Norman 2004; Krippendorff 2006; Sonderegger and Sauer 2010), and to the fact that consumers did not only buy a product, they bought value in the form of entertainment, experience, and certain features of identity (Esslinger 1999; Sheng and Teo 2012). In this sense, based on motivation and context, the perceived attributes of a product could be even more relevant than its tangible properties (Liu 2001). In the present information and knowledge society, cultural and social values conveyed by products are growing in importance. Basically products are sold according to intangible values like aesthetics, style, or the image of those who own them (Lenau and Boelskifte 2003). Thus, multiple methods developed from different fields (psychology, ergonomics, human-computer interactions, engineering, etc.) to evaluate aesthetics, meaning and emotions have emerged during the last few years: "Kansei Engineering" (e.g. Jiao Zang and Helander 2006; Nagamachi 1999), "Empathic Design" (e.g. Luh et al. 2012), "Product Semantic Analysis" (e.g. Alcántara et al. 2005; Karlsson et al. 2003) and "Adaptative Conjoint Analysis", (e.g. Tseng et al. 2012), and many more. These method can be used to measure user's perception and to relate it to a product's formal characteristics. In any case, measuring emotions derived from the interaction with a product proves complicated, specially when it comes to trigger certain users' emotions form the early stages of product design (e.g. conceptual design) (Khalid and Helander 2006; Leblebici-Baçar and Altarriba 2013). Proposals like those of Hsiao and Liu (2004), and Hsiao and Tsai (2005) are a step forward in conceptual modelling derived from cognitive and emotional requirements, although they do not often guarantee technical feasibility of the product and they are based on rigid design rules of difficult and dubious generalization (e.g. Jiao et al. 2006). For this reason the authors seek to introduce an approach which starts from the available, evaluated geometries to extract common features of the successful solutions, and to differentiate them from not so successful ones.

Phenetics is used in biology as a procedure to establish similarities between species by comparing them according to multiple external formal features. This article is based on that grouping method to identify similarities and differences between different drill models. Therefore, the aim is to classify these products according to their morphological similarity and observable features, in order to see to what extent perceptions differ between groups. The goal is to surpass methods which are based on product breakdown in attributes and levels, as for example Kansei Engineering or Conjoint Analysis, and to conduct perceptive analyses starting from the full geometric information of design proposals. Knowing these shapes and basing ourselves on morphological analyses derived from the General Procrustes Method (GPM) (e.g. Lycett et al. 2010), the aim is to validate this approach for industrial products, being its ultimate purpose to delimit the geometrical locus of points in which, within certain limits, design modifications could be made to control the transmission of messages and emotions without altering the product's functional performance.

2 Materials and Methods

The study was conducted following these steps:

- Models digitization and alignment to draw the boundaries of the so-called Product Design Space (PDS), the Functional Invariance Space (FIS), and the Change Space (CS).
- Morphological analysis derived from the Procrustes General Method.
- Grouping of shapes using Hierarchical Clustering Analysis (HCA).
- Assessing perception differences between identified groups

2.1 *Digitization, Model Alignment and Drawing of the PDS, FIS and CS*

Ten different drill models belonging to a common product family were selected. To do so, while also trying to guarantee sufficient geometric variability, ten impact drills with mains power supply chord, power ratings between 420 and 750 W, and speed electronic control were acquired.

In order to be able to analyse morphological information, the drills were digitized. This process was carried out by means of an articulated arm digitizer and the Rhinoceros v3.0 software.

Once the tools were digitized, an alignment criterion was specified to compare the different geometries obtained, and to define the PDS, FIS and CS. In this case the reference for the models' alignment was the drill chuck's center at its outermost end (the point where the drill chuck grasps the drill bit) as depicted in Figs. 1 and 3.

Once the models were aligned, the PDS was determined, which is defined as the total volume envelope which covers all the digitized shapes. At the same time, inside the PDS the following subspaces are obtained: the Functional Invariance Space (FIS) and the Change Space (CS). The FIS is defined by the loci of the points common to all successful shapes, while the CS is defined as the space where modifications could be made on the design to control the transmission of messages and emotions without affecting a product's functional features.

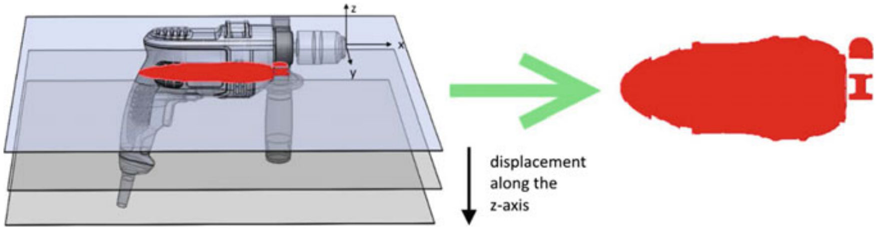

Fig. 1 Model slicing process

2.2 Morphological Analysis Derived from the Procrustes General Method

Firstly, in a first 2D approximation the models were dissected in the plane which split the drills' shape into two identical and symmetrical parts along its longitudinal axis. After that, the ratio between the total area of a drill and the area common to all ten machines' sections, or the FIS as explained before, was computed using these sections.

To that end, once the aforementioned areas and the FIS were obtained, these were exported to Matlab and, by using a small application written in the M language, the coefficient C_e was computed. This coefficient is given by:

$$C_e = \frac{A_i}{A_k}; \tag{1}$$

where A_i is the area of the FIS, and A_k is the total section area of each drill.

In order to find out how each model's Change Spaces influences the way they are perceived, and considering that the General Procrustes Method requires a two-by-two comparison of the various morphologies, it was decided to establish the machine with the greatest coefficient C_e as a reference model, as its geometry, being the most similar to the FIS, would have the smallest CS. This way it is possible to control how the Change Spaces impact the users' perceptive judgements.

Once the machine against which the dissimilarity indexes of all the other machines were be measured was chosen, the 3D models were segmented in order to obtain the 2D slices needed to compute the aforementioned index. These slices were obtained from iterative intersections of horizontal planes parallel to the main body's longitudinal axis of the machines in steps of 3 mm. This process was carried out for all models being studied with the aid of the SolidWorks 2013 software. The height on the vertical axis corresponding to the position where the drill chuck grasps the drill bit, which is the point with respect to which the models were aligned, was used as a geometrical reference point. Figure 1 shows an example of this process along with the resulting slices.

The goal was to compare each machine with the one chosen as a reference model. This was achieved by comparing two-by-two the sections obtained from the slicing operations being made along the z-axis as previously explained with regard to the dissimilarity index. This index is obtained from the General Procrustes Method (Ross 2004), and it is determined with the aid of the Matlab software (Mathworks 2010), in each and every location in which both drills to be compared had a section. The index is computed as follows:

$$d = \frac{\sum_{i=1}^{n} \sum_{j=1}^{p} \left(X_{ij} - Z_{ij}\right)^2}{\sum_{i=1}^{n} \sum_{j=1}^{p} \left(X_{ij} - \bar{X}_i\right)^2}; \tag{2}$$

where X is a matrix which contains the correct row sequence of significant points that belong to the section of the machine to be compared. The first column contains their coordinates on the horizontal axis; the second one, on the vertical axis. The variable n represents the number of significant points available, and the variable p, the number of dimensions of space in which the slices are represented (two in this case). The matrix Z contains the significant points of the reference machine's section appropriately transformed. They were obtained from the matrix of significant points Y, which corresponds to the section of the reference machine, as detailed in Eq. 3.

$$Z = bYT + c; \tag{3}$$

In this equation b is a scaling factor, T is a transformation matrix and c is a displacement vector. These terms are computed in such a way that they minimize the numerator on Eq. 2.

Some modifications were made to the program in order to adapt it to this work's requirements. The Generalized Procrustes Analysis requires a finite series of landmark points for each one of the sections to be compared (Ross 2004). These points should have the same geometric meaning in both (Stegmann and Gomez 2002). To achieve that goal, a selection and sequencing algorithm was developed in Matlab. The algorithm worked on points along each section's perimeter, it determined the rightmost point, and proceeded clockwise along it. Thereby two perimetric vectors, with different lengths and consisting of two different point sequences, were obtained.

Then, the longest perimetric vector was reduced to match the smallest vector's size. In the end the points which form the two perimetric vectors had the same geometrical meaning depending on their location in the sequence, that is, their relative position as we proceed along the sections' perimeters.

Another aspect to be taken into account was the existence of more than one entity on many slicing positions, as Fig. 2 shows. In the specific case of Fig. 2, the additional entity which appears is clearly caused by the auxiliary handle of the drill. Matlab computes the dissimilarity index between two geometrical entities only, therefore we had to establish criteria for its computation in cases where there were more than one entity in a model's slice.

In these cases, the problem of calculating the dissimilarity index was divided into several comparisons which numbered the larger number of entities in the two

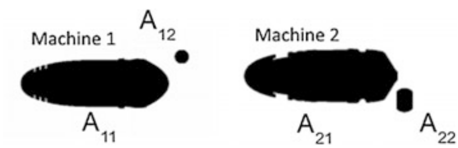

Fig. 2 Comparison of sections with more than one entity per model

slices to be compared. Each of the entities which made up each section or slice was assigned a rank based on its area. Afterwards the dissimilarity indexes were computed by comparing entities with the same rank.

Figure 2 shows the described situation. Firstly the entities A_{11} and A_{21} would be compared, and then entities A_{12} and A_{22}, to obtain dissimilarity indexes d_1 and d_2, respectively. To compute the Procrustes index obtained from the comparison of both sections (Eq. 4), we apply weighting factors which are given by Eq. 5.

$$d = p_1 \times d_1 + p_2 \times d_2; \tag{4}$$

$$p_i = \frac{A_{1i} + A_{2i}}{A_{11} + A_{12} + A_{21} + A_{22}}; \tag{5}$$

Should the number of entities not be the same, a penalization index d_p, given by Eq. 6, is to be added to the total dissimilarity index of Eq. 4. In this expression n is the number of entities on the first slice, m is the number of entities on the second slice, A_{1i} are the area values of each of entities belonging to the first slice, A_{2j} are the area values of entities belonging to the second slice, and $m = n + 1$, so that the entity that remains without counterpart in the other slice is A_{2m}.

$$d_p = \frac{(m + n) \times A_{2m}}{\sum_{i=1}^{n} A_{11} + \sum_{i=1}^{m} A_{2i}}; \tag{6}$$

In doing so, the dissimilarity indexes for each and every section obtained along the x-axis are computed. The total dissimilarity index was defined in order to synthesize this information into a single value. It is given by Eq. 7, in which the geometric mean of all values computed along the z-axis is calculated.

$$d_{total} = \frac{\sqrt{d_1^2 + d_2^2 + \ldots + d_z^2}}{n_z}; \tag{7}$$

2.3 *Machine Grouping Based on Hierarchical Cluster Analysis (HCA)*

Once obtained, the C_e coefficient of each drill and the total dissimilarity index of every drill with respect to the reference model were grouped by using clustering techniques and the SPSS v.16 software. The agglomerative, complete-linkage clustering HCA method was chosen for this task. The squared Euclidean distance was used as a metric and computed from the values obtained from the drills as grouping variables: the C_e coefficients and the total dissimilarity indexes computed for each model.

2.4 Assessment of Differences in Perception Between Groups

The perception assessment was done using the semantic differential method (e.g. Osgood 1957; Artacho et al. 2010). The semantic space was based on the work of Kjetil (2005), although concepts like the hedonic component (I like it/I don't like it), and the user's buying intention were also included. And so the concepts employed were: (1) Modern and Innovative, (2) Reliable and Safe, (3) Ergonomic, (4) Professional, (5) Resistant and Robust, (6) Functional, (7) Visually Attractive, (8) Aggressive and Powerful, (9) I like it, (10) Buying intention.

A specific application platform was developed in order to conduct online surveys. It was implemented using AJAX, the PHP and Javascript languages using the open source CodeIgniter framework. The information gathered in the surveys was stored in a MySQL database.

The user accessed the platform using a browser, he logged in, then he specified information concerning his profile, and after that he evaluated the drills with respect to a group of assertions built upon the semantic concepts of this work (e.g., "*This drill is modern and innovative*"). A total of 125 users did this survey. The users rated their agreement in a 5-point Likert scale coded from −2 to 2, depending on the answer: (−2) Completely disagree, (−1) Disagree, (0) Indifferent, (1) Agree, (2) Completely agree.

Once the drills belonging to each cluster after the grouping process in 2.4 were known, a one-way ANOVA was conducted with significance levels of differences set at $p < 0.05$ in order to determine if there were significant statistical differences in perception between groups. The group identifier was used as factor and the semantic concepts were considered as dependent variables. The Least Significant Difference (LSD) was used as a multiple comparison test to establish groups between which there were differences. Statistical processing was done in SPSS v. 16.

3 Results

Table 1 below shows a photograph of each of the selected drills and their corresponding 3D models obtained after the digitization process.

Figure 3 shows the PDS in 3D, the FIS, and the CS.

Table 2 shows the C_e coefficients of each machine, which were computed for each drill from their digitized model.

The machine with the highest coefficient was drill number 4. Its transverse section suited best to the FIS. This machine's 3D model was chosen as a reference model for the calculation of the dissimilarity indexes of the remaining machines.

Table 1 Real and digitized drill models which were used on this study

Drill identifier	Picture	Model	Drill identifier	Picture	Model
Drill 1			Drill 6		
Drill 2			Drill 7		
Drill 3			Drill 8		
Drill 4			Drill 9		
Drill 5			Drill 10		

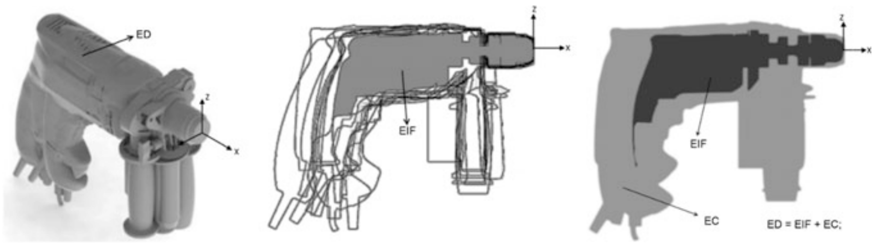

Fig. 3 Product design space (3D), functional invariance space and change space

Table 2 Coefficients relative to functional invariance space

Drill	C_e	Drill	C_e	Drill	C_e
1	0.5907	5	0.6141	9	0.4818
2	0.5865	6	0.4880	10	0.5805
3	0.5773	7	0.6328		
4	0.6719	8	0.5227		

Table 3 Total dissimilarity indexes using drill number 4 as a reference

Drill	d_{total}	Drill	d_{total}	Drill	d_{total}
1	0.0311	5	0.0313	8	0.0451
2	0.0227	6	0.0533	9	0.0477
3	0.0366	7	0.0388	10	0.0406

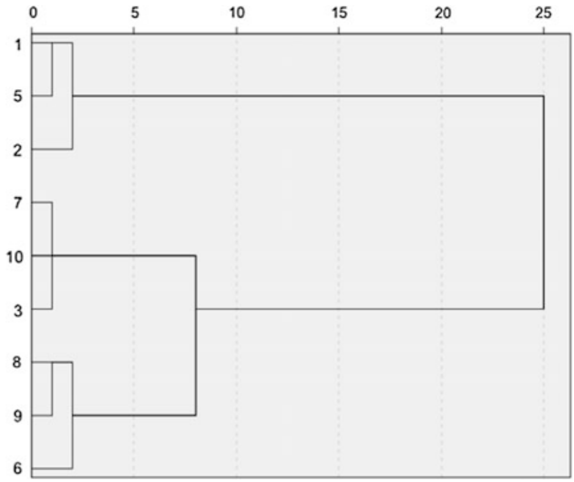

Fig. 4 Clustering dendrogram based on total dissimilarity indexes and C_e

Table 3 shows the dissimilarity indexes obtained. The lower the value of the index, the more similar are the compared machines from a Generalized Procrustes Analysis perspective. The machine most similar to the reference model was drill number 2, while the most dissimilar was drill number 6.

The dendrogram resulting from the hierarchical cluster analysis is shown in Fig. 4. There are three machine groups: group 1, formed by drills 1, 2 and 5, group 2, formed by drills 6, 8 and 9, and group 3, formed by drills 3, 7 and 10. The drills belonging to each group are shown in Fig. 5. Group 1 is the most similar to the reference machine, group 3 being the most different.

Table 4 summarizes ANOVA results after the post hoc test. Only those concepts between which there were significant differences for $p < 0.05$ are shown.

4 Discussion

This approach based on phenetics and morphological analysis offers very positive results in studying the influence of form over perception. On its basis the concepts of PDS, FIS and CS have been introduced (Fig. 3). In this context, the FIS is formed by the loci of the points which define the absolute minimum space to guarantee a drill's most basic functionalities. On the other hand, the CS

Fig. 5 Groups obtained from HCA

Table 4 Post-hoc test results

Concept	Groups with significant differences	Mean differences	Signification level
Modern and innovative	Group 2 with group 3	−0.233	0.045
Professional	Group 1 with group 2	−0.289	0.010
Resistant and robust	Group 1 with group 2	−0.465	0
	Group 1 with group 3	−0.430	0
Aggressive and powerful	Group 1 with group 2	−0.428	0
	Group 1 with group 3	−0.235	0.009
	Group 2 with group 3	0.193	0.035
Buying intention	Group 1 with group 2	−0.246	0.047

encompasses the space where changes affecting the form can be done without affecting its primary function as a drill. With this we could claim that this approach encompasses both the sphere of influence and the competence of two different professional profiles related to design activities: on the one hand the product engineer, on the other, the industrial designer. The FIS is the volume available to product engineers to guarantee its basic functionality by encapsulating the required technology. It is where the most relevant subsystems, components and parts are to be included so that the product achieves its main purpose. The CS is the portion of space where form can be worked on freely to adjust it, and to work on it in a more ergonomic way, adapting it to usage and to aesthetic and symbolic demands; it is the space where industrial designers encapsulate through form and formal attributes the messages they want to transmit. This can obviously be considered a simplification of reality, although it has sense in a conceptual way and it is useful as a first approach.

In this study the selection of the reference machine, which has the smallest CS, has been made by computing the C_e index for all of them (see Table 2). This machine is the most similar to the FIS of all the machines being studied. This way morphologic differences relative to the CS between itself and the other machines could be evaluated, as well as perception associated with the drills. In doing the grouping using hierarchical cluster analysis, the conclusion that these morphological differences can generate distinct perceptions in a statistically significant way can be drawn. We would like to emphasise that machines belonging to group 2 reflect a better buying intention than those of group 1, machines of groups 2, and 3 are perceived as more aggressive and resistant than those of group 1, elements of group 2 are perceived as more professional than those of group 1, and, finally, machines of group 3 are seen as more modern and innovative as the ones on group 2. It is also possible, though in a qualitative way, to draw formal attributes from machines belonging to the same group that differentiate them from other groups. For example, machines belonging to group 1 have a central body which is curved, with irregular shapes on the top, and which is shorter than other body types; cooling vents have a similar configuration and are slightly slanted towards the main drill handle. The machines in group 2 are clearly the biggest ones, with an elongated central body and a similar curved configuration for the main handle, specially for machines 6 and 9. One last thing, group 3 is made up of sharp-edged machines with many angular features on the central body and an identical shape on the lower main handle, which is way less pronounced than in other groups.

The differences founded between groups allow validation of this approach and of the given definitions of design spaces and subspaces. This approach also allows us overcome the implicit limitation of classic approaches (e.g. Kansei Engineering, Conjoint Analysis), which require the breakdown of products in attributes and design features, and it provides a method which allows to perform this analysis taking into account the whole geometry of the design.

We shall mention that the term *design space* appears in literature in a work by Bardill et al. (2007), although having only theoretical nature while also being part of the exposed Product Envelope. These authors note that the design space contains all the valid functional solutions to carry out its function, and it constitutes its model's core. This core is enveloped by a series of dimensions ranging from contemplation of cognitive and emotional information made by users about the solutions, through dimensions which include design of the service which encompasses the product, to the kind of experience to be generated. The described model's materialisation would lay down relations between emotions and sensations, and the physical and spatial distribution represented by the product's form. In this sense, it is important to stress the contributions made in the field of *shape grammars* (e.g. Duarte 2005; Jowers and Earl 2011). On these, design spaces are portions of space governed by physical and functional restrictions. However, in spite of the physical translation of the design space concept, most applications in this scope are limited to architecture and the generation of 2D geometries to optimise plant layout in buildings.

The concept of design space in a spatial and geometric sense also appears in the work of Artacho et al. (2010), although the definition is limited to formal design spaces in such a way that spatial boundaries between alternatives are defined. These alternatives transmit certain cognitive, emotional, and buying intention aspects with statistical significance. However, in this work progress has been made regarding the analysis of latent information available inside the morphology of products, adding the mentioned spaces and subspaces, all of which gives the analysis greater insight and represents an advancement in the problem of analysing form from a symbolic, engineering and teleological perspective.

Methodogically, emphasis must be given to the programmed algorithm which significantly augments the number of points with equivalent geometric significance in each of the sections to be compared. There are many works in other fields, like paleontology (e.g. Marcus et al. 2000), in which the number of significant points does not exceed 30. However, with the algorithm used hundreds of points are considered, which provides better accuracy in computing the morphological dissimilarity indexes.

The computation of the formal dissimilarities for each value along the z-axis (in 3 mm increments), the C_e values, and the final computation of the total dissimilarity index have us allowed to compare 3D morphologies through a 2D morphological analysis. Applying the Procrustes method directly on the (X, Y, Z) point coordinates of the morphologies to be compared, as well as establishing more detailed relationships between morphology and perception remain pending for future works. Furthermore, as we focusing on geometrical analysis of the form, external attributes like colour are out of the scope of this study and should be taken into account in future works.

5 Conclusion

Phenetics and morphological analysis by the use of the General Procrustes Method make possible to analyse, classify and differentiate forms of products which produce differences in perception among themselves. This approach introduces the concepts of Product Design Space, Functional Invariance Space and Change Space, and gives them a geometric interpretation by splitting the minimum volume needed to guarantee the functionality of a particular product from the space free of basic functional issues, and therefore destined to formal design and fitness for use.

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Part IV
Environmental Engineering and Natural Resource Management

Optimization of the Location of the Municipal Solid Waste Bins Using Geographic Information Systems

Mar Carlos, Antonio Gallardo, Mónica Peris and Francisco J. Colomer

Abstract Nowadays, in the Spanish cities streets there are several types of bins to collect the different municipal solid waste (MSW) fractions: organic matter and reject fraction, paper and cardboard, light packaging, glass, used oil, clothes, etc. To locate them correctly in the urban landscape is an important task in the MSW management. In the first place, from the MSW collection point of view, a appropriate bins location makes their collection easier. In the second place, in the selective collection, a good location is basic to ensure the citizens participation in the recovery of the recyclable materials. Moreover, the bins location must respect the urban environment. This work presents a methodology to optimize the MSW bins location taking into account several factors such as the distance to the users, the streets characteristics, the presence of singular urban points, etc. The methodology will be later applied to the optimization of the location of the different waste fraction bins of a Spanish city using the Geographic Information Systems (GIS).

Keywords Optimization · Location · Bins · MSW · GIS

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1 Introduction

From an economic point of view, the Municipal Solid Waste (MSW) collection represents an important part of the cost of the MSW management. This is due to staff salaries, the maintenance of the collection truck fleet and the fuel consumption of these trucks. In Spain, bigger towns have a higher service costs (Jofra et al. 2011). For this reason, many authors have focused their studies on new methodologies to optimize the MSW collection and transport. In Greece, where the MSW collection and transport costs can be higher than 70 % of the total MSW management costs, Chalkias and Lasardi (2009) proposed a methodology to improve the efficiency of the waste collection and transport by reallocating the bins and optimizing the distance and time of the collection routes. Arribas et al. (2010) proposed a methodology to design an MSW collection system focused on combinatory optimization and integer programming as well as the use of Geographic Information System (GIS) to minimize the collection time, the transport and operation costs.

The selection of an MSW management system is also a key factor from the environmental point of view. Mühle et al. (2010) compared the MSW management in Germany and the United Kingdom. The results of this work shows that in a German-like MSW recycle management the amounts of Carbon emissions are up to five times higher. But in order to recover and recycle materials it is necessary to previously implement a selective collection system. This fact complicates the management as it means that the number of bins as well as the number of collection trucks increase. For this reason, the new technologies are becoming a good support in MSW management. That is the case of the identification systems of radio frequencies and global location systems (Faccio et al. 2011) or the Web-GIS strategies (Rada et al. 2013). These systems are useful to define the filling status of the bins and therefore to stablish the optimum routes and collection frequencies.

Anyway, before planning the MSW collection, some previous studies about the town characteristics and needs should be done. Kao and Huang in 2013 proposed six optimization models focused on three objectives to minimize the service distance by maximizing the service tax and reducing the number of disposal areas for three scenarios; base district, open district and no district.

The present work tackles this first part about management planning studying factors such as MSW generation tax and the number of bins required depending on the number of inhabitants. Moreover, the optimum location of these bins has been studied taking into account the distance to the citizen's housing and location points where they do not disturb the rest of the urban services.

2 Objectives

The main aim of this work is to present a methodology to optimize the number of bins for the MSW recovery fractions (paper-cardboard, glass and light packaging) in a town as well as their location. To calculate the amount of bins, the distribution of the inhabitants in the town, the MSW generation rate for each fraction and the location of the doorways should be previously determined. With all these data, the first step will consist in identifying the current number of bins per inhabitant and the distance of the inhabitants to their nearest bin. From these results, if needed, a possible relocation of the bins will be studied. This new location should place the disposal point at an adequate distance from the inhabitants in order to facilitate them waste disposal task and; therefore, contribute to improve the MSW separation rate. In this paper, the current situation of the bins distribution in the town will be compared to the optimized situation obtained after applying the methodology proposed.

3 Methodology

The methodology proposed to ensure an efficient reallocation of the bins consists of the following steps:

- Analysis of the current situation of the town.
- Determination of the waste generation rate.
- Optimum location of the bins.
- Comparison of the results.

All the steps have been applied to a real case, the town of Castellón de la Plana (Spain).

3.1 Analysis of the Current Situation

As mentioned before, the first step consists of describing the current situation. At this point, the total number of bins per fraction must be recorded and they must be exactly located in the street net. For this reason, firstly, a digitalized street network correctly updated and connected must be drawn. The base geography in the case of Castellón was obtained from the Spanish National Cartographic Institute (Instituto Cartográfico Nacional) data. The main advantages of these data are that they are in the correct format file to be used in the informatics tool ArcGis and the access to them is free. These data have been cleaned and updated. The main changes in these data have been the correction of street and roundabouts layouts, the addition of the directions of traffic including no entry streets and prohibited turnings. Moreover, the new neighbourhoods, which were not in the initial street network, have also been added. Consequently, 3.126 lines have been drawn which are equivalent to 280.5 km of streets. The street network is necessary to calculate the distances between the different elements: users and bins.

The second step is to specify the distribution of the inhabitants in the entire urban area as well as the access to the doorways. The number of inhabitants can be obtained from the census of the municipal districts or the Municipal Register of Inhabitants. This data will be useful to determine, together with the waste daily generation rate, the amount of waste generated in the town.

With this previous data and knowing the number and the location of the doorways in the entire town, the average number of inhabitants per doorway can be calculated. This value will allow calculating the distance that the citizens must cover from their doorways to the nearest bin.

3.2 Determination of the Waste Generation

The number of bins per waste fraction to locate is calculated taking into account the total volume of waste generated per fraction. Therefore, in the first place, the amount of waste of fraction j, G_{ij} should be calculated as Eq. (1) shows. It should be calculated considering the number of inhabitants and the daily generation rate of fraction j (DGR_j).

In the second place, the waste volume in the bins should be calculated (Eq. 2) in reference to the number of inhabitants, the DGR_j, the coefficient of utilization (Cu) and the waste density for fraction j (D_j). The Cu is calculated by dividing the biggest waste monthly generation rate of a year by the annual average.

Finally, the weekly volume of a fraction j deposited depends on the number of inhabitants, the DGR_j, the collection frequency (Fr), the Cu and the D_j as Eq. 3 shows:

$$G_{ij} = Inhab \cdot DGR_j \tag{1}$$

$$V_{ij\_daily} = Inhab \cdot DGR_j \cdot Cu/D_j \tag{2}$$

$$V_{ij\_weekly} = Inhab \cdot DGR_j \cdot Fr \cdot Cu/D_j \tag{3}$$

where:

i	is the bin;
j	is the waste fraction;
G_{ij}	is the amount of waste of fraction j deposited in bin i in kg;
V_{ij}	is the volume in every point for each fraction in m^3;
Inhab	is the number of inhabitants per disposal point;
DGR_j	is the daily generation rate of fraction j in kg/inhab day;
Cu	is the coefficient of utilization;
Fr	is the collection frequency;
D_j	is the waste fraction j density in the bin in kg/m^3

3.3 Optimum Location

When the number of bins needed is known, the following step is to locate them correctly. First, the possible disposal points must be defined on the street network. To select, some factors should be considered. For example, they must be safe points for the user, they must be accessible points for the collection vehicles, they must allow the circulation of the rest of vehicles and the cultural heritage must be preserved. The general recommendation to define the possible disposal point is to fix them at cross streets and at intermediate points of long streets without cross streets.

4 Results

4.1 Current Situation

This methodology has been applied to the town of Castellón de la Plana (Spain) that in 2012 had 156,221 inhabitants. The linear density of the population in this town is shown in Fig. 1. The current location of the bins can be obtained from data provided by the town council or from fieldwork. Once the possible disposal points are located on the network, it is important to know the distance that a user must cover from his

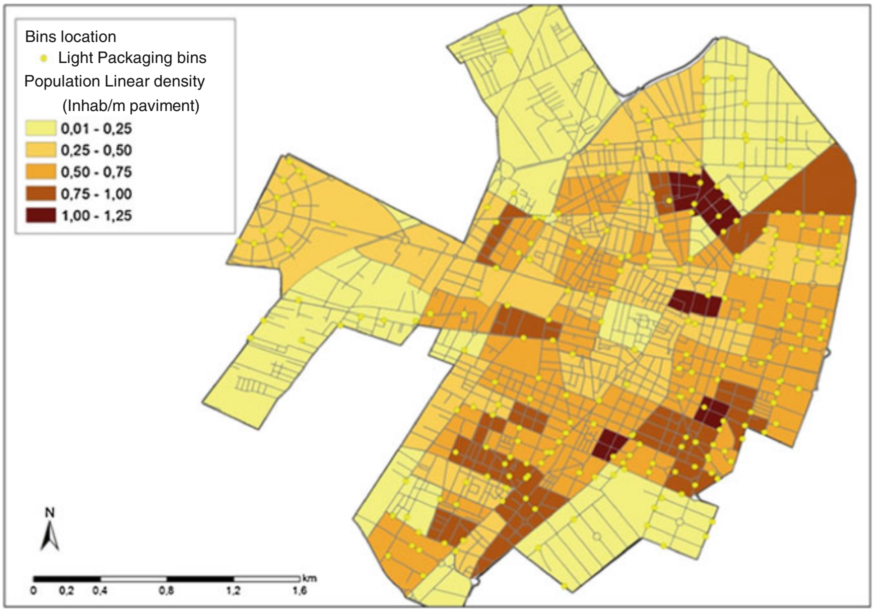

Fig. 1 Population density in the town and location of the light packaging bins

Table 1 Actual distance between bins of the same fraction: CP, CV and CE

Distance (m)	N° PB	% PB	N° GB	% GB	N° LB	% LB
0–50	44	18.50	26	11.82	46	18.78
50–100	109	45.80	103	46.82	121	49.39
100–150	57	23.95	57	25.91	51	20.82
150–200	18	7.56	23	10.45	18	7.35
200–250	7	2.94	10	4.55	7	2.86
250–300	3	1.26	1	0.45	2	0.82

house to the nearest bin as it is one of the success factors of the waste selective collection (Gallardo et al. 2010). After an exhaustive fieldwork, 238 Paper and cardboard bins (PB), 220 Glass bins (GB) and 245 Light packaging bins (LB) have been located on the street network.

Table 1 shows the current distance between bins of the same waste fraction in the town.

The data in Table 1 shows that in this town, most of the bins of the same fraction are separated by a distance between 50 and 100 m. Particularly, 45.80 % of the PB, 46.82 % of GB and 49.39 % of LB are in this range. Additionally, 11.76 % of PB, 15.45 % of GB and 11 % of LB are at distances between them greater than 150 m.

Moreover, in Castellón, there are 13,771 doorways. Table 2 shows the distances from these doorways to the nearest PB, GB and LB. Once these distances have been calculated, they have been classified in different ranges and the percentage of doorways within every range has been calculated.

Attending to data in Table 2, it can be said that 65.68 % of the doorways have a PB at a distance less than 150 m, 83.3 % at a distance of less than 200 m and 93 % at a distance less than 300 m. Similar data has been found for the other waste fractions. In the case of the glass fraction 64.11 % of the doorways have a GB at a distance less than 150 m, 83.03 % at a distance less than 200 m and 95.15 % at a

Table 2 Percentage of doorways attending to the distance to the bin

Distance (m)	% Doorways PB	% Doorways GB	% Doorways LB
0–50	13.11	12.53	13.56
50–100	23.60	22.82	23.93
100–150	28.97	28.76	28.58
150–200	17.62	18.92	17.04
200–250	7.14	8.34	7.24
250–300	2.55	3.76	2.53
300–400	2.08	2.61	2.04
400–500	2.18	1.76	2.21
500–600	1.31	0.33	1.33
600–700	0.81	0.04	0.84
700–800	0.53	0.04	0.59

Fig. 2 Route covered from the doorway to the nearest GB

distance less than 300 m. Finally, regarding the distance to the LB 66.07 % of the doorways have an LB at a distance less than 150 m, 93.11 % at a distance less than 200 m and 92.88 % at a distance less than 300 m. Figure 2 shows the route covered from each doorway to the nearest GB.

Taking into account the distribution of the population and the location of the doorways on the city map, the average number of inhabitants per doorway and the distance that the users must cover from their houses to the nearest bin have been calculated. The results have been organized according to the length travelled and the percentage of inhabitants that cover the route from their houses to each of the types of bins PB, GB and LB as Table 3 shows.

Results in Table 3 reflect that around 70 % of the population have a bin of each fraction at a distance of less than 150 m from their house. Particularly, 74 % of the inhabitants have a PB, 72 % of the users have a GB and 75 % have a LB at a distance of less than 150 m. It can be said that almost 90 % of the population have a selective collection container at a distance less than 200 m from their homes, 89 % have a LB and a PB and 88 % have a GB at a distance less than 200 m from their homes. Figure 3 shows an example of how ArcGis 10.1 links every doorway with its nearest bin.

The following step consists of calculating the DGR for each waste fraction as well as the bin volume needed, taking into account different collection frequencies: fortnightly collection (Fr = 15), weekly collection (Fr = 7), twice a week (Fr = 3.5) collection or three times a week (Fr = 2.3) collection, using Eqs. (1), (2) and (3).

Table 3 Percentage of inhabitants according to the distance to the bin

Dist. (m)	% Inhab. to PB	% Inhab. to GB	% Inhab. to LB
0–50	20	19	20
50–100	27	26	27
100–150	28	28	27
150–200	14	16	14
200–250	5	6	5
250–300	2	2	2
300–350	1	1	1
350–400	1	1	1
400–450	1	1	1
450–500	1	0	1
500–550	1	0	1
≥550	0	0	0

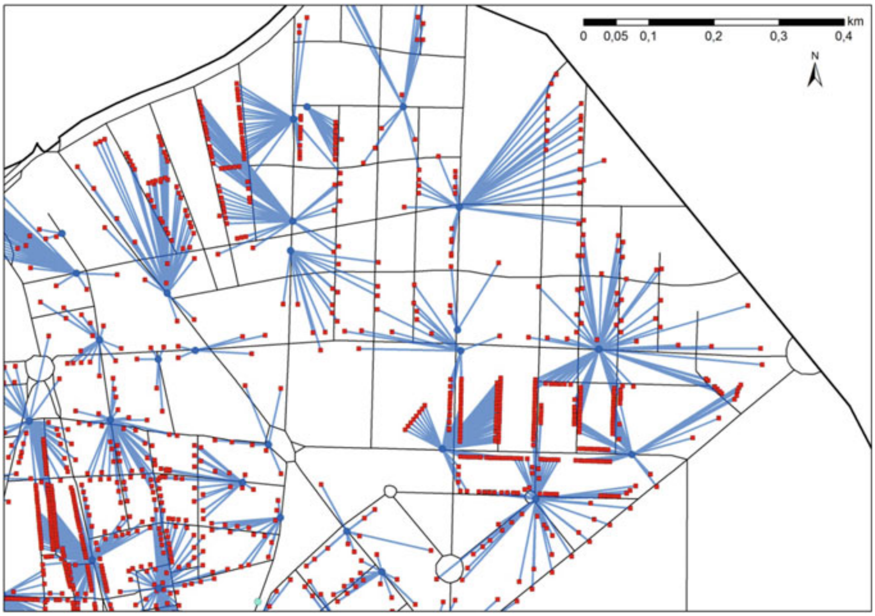

Fig. 3 Linking doorways to the neares PB

The waste densities used are 90 kg/m^3 in the case of the paper-cardboard fraction, 364 kg/m^3 in the case of the glass fraction and 80 kg/m^3 in the case of the glass fraction (Di Maria and Micale 2013). Tables 4, 5 and 6 show the maximum, minimum and average values obtained for each waste fraction. With this data the moments when the bins will be completely filled can be determined. Consequently the number of bins or the collection frequency needed will be also determined.

Table 4 Waste volume in LB

	N° inhab./bin	DGR (kg/day)	$Vol_{(daily)}$ (m^3)	$Vol_{(weekly)}$ (m^3) (Fr = 2.3)	$Vol_{(weekly)}$ (m^3) (Fr = 3.5)	$Vol_{(weekly)}$ (m^3) (Fr = 7)	$Vol_{(weekly)}$ (m^3) (Fr = 15)
Min.	15	0.31	0.00	0.01	0.01	0.03	0.06
Max.	2391	47.82	0.65	1.48	2.26	4.52	9.68
Average	640	12.81	0.17	0.40	0.61	1.21	2.59
Standard deviation	528	10.56	0.14	0.33	0.50	1.00	2.14
$V \geq 3.2\ m^3$						15	78

Table 5 Waste volume in GB

	N° inhab./bin	DGR (kg/day)	$Vol_{(daily)}$ (m^3)	$Vol_{(weekly)}$ (m^3) (Fr = 2.3)	$Vol_{(weekly)}$ (m^3) (Fr = 3.5)	$Vol_{(weekly)}$ (m^3) (Fr = 7)	$Vol_{(weekly)}$ (m^3) (Fr = 15)
Min.	15	0.31	0.00	0.00	0.00	0.01	0.02
Max.	2437	48.74	0.17	0.40	0.60	1.21	2.59
Average	718	14.36	0.05	0.12	0.18	0.36	0.76
Standard deviation	567	11.33	0.04	0.09	0.14	0.28	0.60
$V \geq 3.2\ m^3$							

Table 6 Waste volume in PB

	N° inhab./bin	DGR (kg/day)	$Vol_{(daily)}$ (m^3)	$Vol_{(weekly)}$ (m^3) (Fr = 2.3)	$Vol_{(weekly)}$ (m^3) (Fr = 3.5)	$Vol_{(weekly)}$ (m^3) (Fr = 7)	$Vol_{(weekly)}$ (m^3) (Fr = 15)
Min.	15	1	0.01	0.02	0.03	0.06	0.12
Max.	2373	95	1.23	2.84	4.32	8.64	18.51
Average	660	26	0.34	0.79	1.20	2.40	5.14
Standard deviation	529	21	0	1	1	2	4
$V \geq 3.2\ m^3$					10	75	129

Attending to the results in Table 4 and knowing that the bin volume in Castellón is 3.2 m^3, it could be said that with a weekly collection frequency in the case of the LB, 15 bins would overflow.

Table 5 shows that there are no overflows in GB even with a fortnightly collection.

In the case of paper and cardboard, as Table 6 shows, if the waste is collected twice a week, there are 10 points locations overflows.

4.2 Bins Relocation Proposal

Additionally to calculating the filling rate of the containers, the determination of the containers filling, a new bin relocation has been proposed for each waste fraction. Therefore, in the first place the ideal location points have been defined. Crossings are, together with intermediate points in long streets, possible ideal points. They have been marked on the map in Fig. 4. As a result, 1503 points have been considered in this figure as possible ideal points.

Once the possible ideal points have been defined, the optimum location of the bin has been calculated taking into account that the distance to be covered by the user must be less than 150 m and that the number of disposal areas should be kept at a minimum. The final disposal areas to locate the bins are shown in Fig. 5. A total of 271 areas have been registered in this map.

With this new relocation, the distance between a doorway and the nearest disposal point can be found on Table 7.

Finally, using Eqs. (1)–(3), the volume to be deposited in each disposal area has been obtained for each waste fraction. The values for LB are shown in Table 8, the values for GB in Table 9 and the values for PB in Table 10. With these data the optimum collection frequency for each waste fraction or the need for additional bins in a disposal point have been determined.

Fig. 4 Location of ideal points

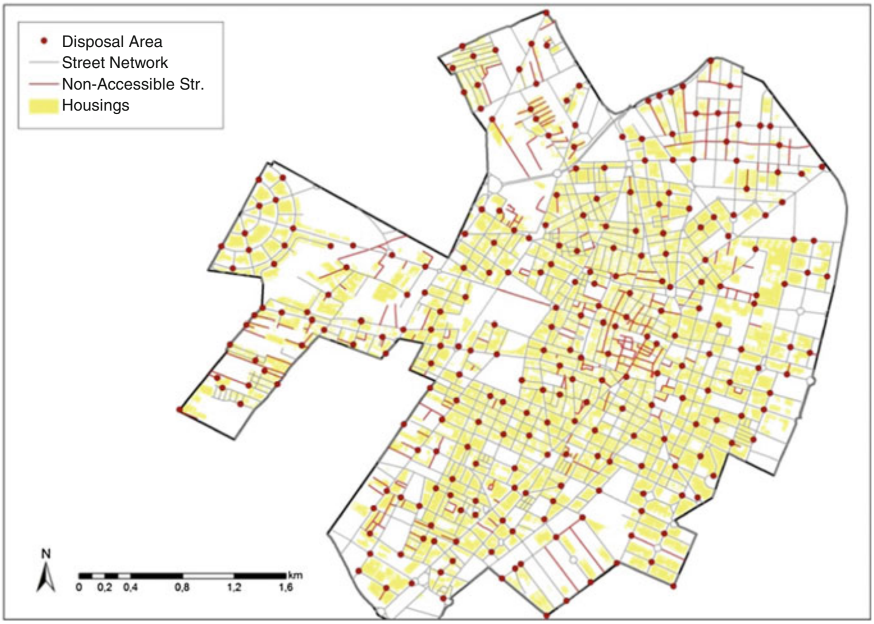

Fig. 5 Proposal of disposal points location

Table 7 Percentage of inhabitants and doorways depending on the distance to the disposal area

Distance (m)	% Doorways	% Inhabitants
0–50	30.95	32.03
50–100	44.42	41.85
100–150	24.63	26.14

Table 8 Waste volume in LB at the new locations

	N° inhab./bin	DGR (kg/day)	$Vol_{(daily)}$ (m^3)	$Vol_{(weekly)}$ (m^3) (Fr = 2.3)	$Vol_{(weekly)}$ (m^3) (Fr = 3.5)	$Vol_{(weekly)}$ (m^3) (Fr = 7)	$Vol_{(weekly)}$ (m^3) (Fr = 15)
Min.	4	0.08	0.00	0.00	0.00	0.01	0.02
Max.	1785	35.70	0.48	1.11	1.69	3.37	7.23
Average	568	11.37	0.15	0.35	0.54	1.07	2.30
Standard deviation	424	8.48	0.11	0.26	0.40	0.80	1.72
$V \geq 3.2\ m^3$						1	77

Table 9 Waste volume in GB at the new locations

	N° inhab./bin	DGR (kg/day)	Vol $_{(daily)}$ (m^3)	Vol$_{(weekly)}$ (m^3) (Fr = 2.3)	Vol$_{(weekly)}$ (m^3) (Fr = 3.5)	Vol$_{(weekly)}$ (m^3) (Fr = 7)	Vol$_{(weekly)}$ (m^3) (Fr = 15)
Min.	4	0.08	0.00	0.00	0.00	0.00	0.00
Max.	1785	35.70	0.13	0.29	0.44	0.89	1.90
Average	568	11.37	0.04	0.09	0.14	0.28	0.60
Standard deviation	424	8.48	0.03	0.07	0.11	0.21	0.45
$V \geq 3.2$ m^3				0	0	0	0

Table 10 Waste Volume in PB at the new locations

	N° inhab./bin	DGR (kg/day)	Vol$_{(daily)}$ (m^3)	Vol$_{(weekly)}$ (m^3) (Fr = 2.3)	Vol$_{(weekly)}$ (m^3) (Fr = 3.5)	Vol$_{(weekly)}$ (m^3) (Fr = 7)	Vol$_{(weekly)}$ (m^3) (Fr = 15)
Min.	4	0.15	0.00	0.00	0.01	0.01	0.03
Max.	1785	71.40	0.93	2.13	3.25	6.50	13.92
Average	568	22.74	0.30	0.68	1.03	2.07	4.43
Standard deviation	424	16.96	0.22	0.51	0.77	1.54	3.31
$V \geq 3.2$ m^3					1	66	152

5 Conclusions

The MSW collection represents a great part of its management. In the towns with selective collection, more bins and collection trucks participate in the process and, consequently, this fact complicates the management. Moreover, to achieve a successful selective collection it is important to locate bins for the different waste fractions at accessible points and near the citizen's houses.

The distribution of the inhabitants in a town and the bins location are crucial factors to take into account to ensure the citizen participation in the waste separation. The location of the bins, as mentioned before, must take into account the proximity to the citizens and furthermore it must respect the operation of other types of town activities.

This work analyses the location of the PB, GB and LB of a Spanish city establishing first of all the distance between the bins. The study finds that most bins of the same fraction are separated between 50 and 100 m. In any case, there are some bins separated by distances greater than 100 m. Particularly, 11.76 % of the PB, 15.45 % of the GB and 11 % of the LB are in this situation.

In the second place, the distance between the user and the nearest bin has been analysed. It has been calculated that approximately 70 % of the population have a bin of each fraction at distance less than 150 m from their doorway, with slight variations depending on the waste fraction. To increase the waste recovery rate the distance doorway-bin of the remaining 30 % of the population would have to be reduced the distance doorway-bin for the remaining 30 % of the population.

Based on these data and on the generation rate for each MSW fraction, the appropriate collection frequency has been analysed.

In the case of the GB no overflows have been detected even with a fortnightly collection frequency. In the case of the LB, it has been calculated that a weekly collection frequency will cause bin overflow in 15 points. For the PB, a collection frecuency of twice a week will cause overflows in 10 points. To mitigate bin overflow the collection frequency should be increased to twice a week in the LB case and to three times a week in the PB case. Another option could be to strengthen the critical points detected on the map with an additional bin.

Furthermore, this study has proposed new locations for the bins. Therefore, in the first place some suitable points have been defined. Of thos defined a total of 271 points have been selected. The selected points must meet some requirements such as they must cover all the housings and every doorway should be less than 150 m away from the bin. The location of these new points represents a better distribution of the disposal areas in the town as most of them are at a distance of 100 to 200 m from any doorway. A bin per fraction should be located in each disposal point. As a result, 30 additional LB, 56 GB and 36 PB should be placed. With the proposed bin distribution all the population would have a bin for each fraction near their housing and consequently it would improve the waste selective collection.

Together with the new location of the bins, an appropriate frequency collection has also been defined to avoid overflows. The results shows that the frequency collection of LB and PB would be twice per week and the collection frequency of GB would be a fortnightly.

This paper presents a methodology that can be applied to any town in order to study the best location of the waste bins in the town streets and their redistribution around the town to improve the citizen's participation in the waste selective collection process.

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Part V
Energy Efficiency and Renewable Energies

Photovoltaic Installations for Self-consumption in Buildings: Feasibility Analysis and Determination of Optimal Design Parameters for the Project

D. Encinas, F. López, C. Segador, J.M. Cosme and L. Cuadros

Abstract In some building typologies with stable electricity consumption profiles in the middle hours of the day, solar photovoltaic technology has emerged as a source of energy that can replace a high percentage of the electrical supply from the conventional power grid. This paper analyzes the photovoltaic energy installations for self-consumption in public buildings of two types from the energy point of view, and reviews the financial aspects. To do this, a software tool which applies recognized models for the prediction of photovoltaic intraday productions has been applied. This tool compares the photovoltaic energy productions with the typical energy demand curves of thirty public buildings and makes the energy and economic balances. The analysis is used for the project decision making regarding the proper location for the installation of panels and the determination of the optimal design parameters of the self-consumption photovoltaic installations to be built in two of the buildings analyzed. In conclusion, for the typical profile of energy consumption of administrative and service buildings, such installations are of interest from the economic and energetic point of view discussed in the article.

Keywords Photovoltaic · Energy self-consumption · Energy efficiency · Efficient buildings

1 Introduction

The results presented in this paper were obtained by doing a feasibility study of photovoltaic systems for self-consumption in public buildings of the Region of Extremadura in Spain. This feasibility study was carried out through the

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ALTERCEXA II project, under the European Union Operational Programme for Regional Cross-border Cooperation of Spain and Portugal.

In general terms, photovoltaic energy self-consumption can be defined as the production of photovoltaic energy in the same place (i.e. on the roof of a building for administrative use) where it is consumed.

The decrease of costs of turnkey solar photovoltaic installations in recent years, the foresight that this situation will remain in the future, together with the increased cost of the electric power delivered through conventional power grids, has resulted in many countries, such as Spain, in a situation in which this photovoltaic self-consumption installations can be attractive alternatives for some typologies of electricity consumers. Figure 1 shows the forecast of the evolution of costs of implementation of solar photovoltaic installations in Spain in accordance with the Spanish Institute for Energy Saving and Diversification.

Several kinds of photovoltaic self-consumption can be defined taking into account whether the energy produced by the photovoltaic installation is stored or not or whether the photovoltaic installation is working in parallel with the conventional power grid in order to have a "backup supply" for the energy production.

In the cases under study, the self-consumption model considered in all the buildings has been the "instantaneous photovoltaic self-consumption model". In this model, the excess of photovoltaic energy production is "injected" into the power grid that supplies electricity to the building and the deficit of photovoltaic energy production is taken from it. Thus, the photovoltaic installation is working in parallel with the conventional power grid.

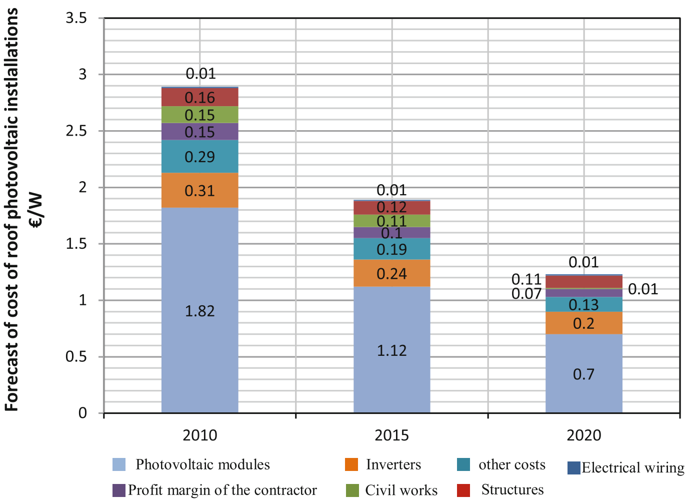

Fig. 1 Cost evolution of roof photovoltaic installations (€/W) according to the Spanish institute for energy saving and diversification. Based on data from of the Institute of Energy Saving and Diversification and the Boston Consulting Group

Working this way, to improve the performance of the photovoltaic self-consumption system, the hourly curve of photovoltaic energy productions should fit as much as possible the hourly curve of energy consumption along the day so that there is no need to take power from the conventional grid nor inject excess of production of photovoltaic energy into it.

The model has been applied to various types of buildings, mainly administrative and sanitary ones.

2 Objectives

The main objective of the study is to determine criteria to optimize the design of this kind of renewable energy installations in the typologies of buildings under study. The goal is to cover the maximal energy demand possible in the building taking into account the best financial parameters for the project.

Using the methodology described in point number below, thirty public buildings of various typologies belonging to the Regional Administration of Extremadura have been analyzed. An extrapolation of the results obtained by typologies of buildings and types of electrical supply contracts has been performed on a total of eighty buildings. The technical and financial parameters obtained have been used to quantify the environmental, economic and job creation benefits.

With the results obtained, two public buildings have been identified to implement photovoltaic installations for self consumption. These installations have been finished on the year 2014 and will be demonstrative and informative of the benefits of this type of renewable energy installations.

For the determination of the optimal power for the sizing of the installations, a software tool has been used to calculate the technical and financial parameters of the project in an iterative process.

3 Methodology

To determine the feasibility of a photovoltaic energy system for self-consumption is essential to know the behavior of the instant electric power demand of the building throughout the day in the various situations all through the year. The factor that most influences such behavior is consumption due to heating in winter and cooling in summer, which can represent about 60 % of the energy consumption of an administrative or sanitary building.

The key is to determine the graph of instant power demand vs. time all through the day in the day types for the various situations that can occur during the year (i.e. the various seasons of the year usually have different daily profiles of energy demand of the building). Later on, the graph of instant power demand of the day type in a specific situation can be compared with the theoretical model of the photovoltaic energy generation during the day expressed also in instant power generated in front of time.

Thus, an electric power analyzer to monitor and register the energy consumption and the instant power demand of the building was installed in the buildings studied. This analyzer recorded the data of instant power demanded versus time every fifteen minutes for two working weeks of the relevant building in the various situations of the year. This way the energy demand patterns were determined.

The data collected allowed the characterization of the energy demand profiles of the working days and the non-working days (i.e. Sundays) and to getting the relevant graphs of instant power demand vs. time of the various day types.

The graphs obtained with the data recorded by the power analyzer for each building have the appearance shown in Fig. 2, corresponding to the power consumption of a sanitary building along one week of measures by registering the power demand every fifteen minutes. The various profiles of instant power demands along the week can be observed.

With these data it is possible to determine a "working day type" and a "non-working day type" for different situations of the year. The profiles obtained are therefore those of "non-working day", "winter working day type", "summer working day type", and eventually intermediate situations that correspond to times of the year in which the HVAC does not have to heat or cool the building and so it has not a big influence in the energy consumption of the building (i.e. springtime). These profiles have been called "day types without heating or cooling".

After determining the profiles of the "day types", daily graphs similar to the one that can be observed in Fig. 3 are obtained. Large differences in the energetic

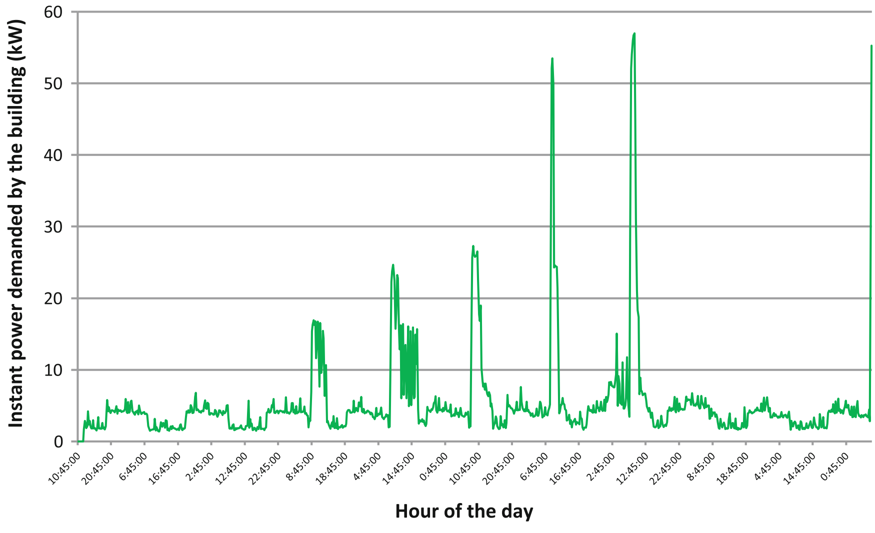

Fig. 2 Instant power demand data registered every 15 minutes along one week in a sanitary building of the sample

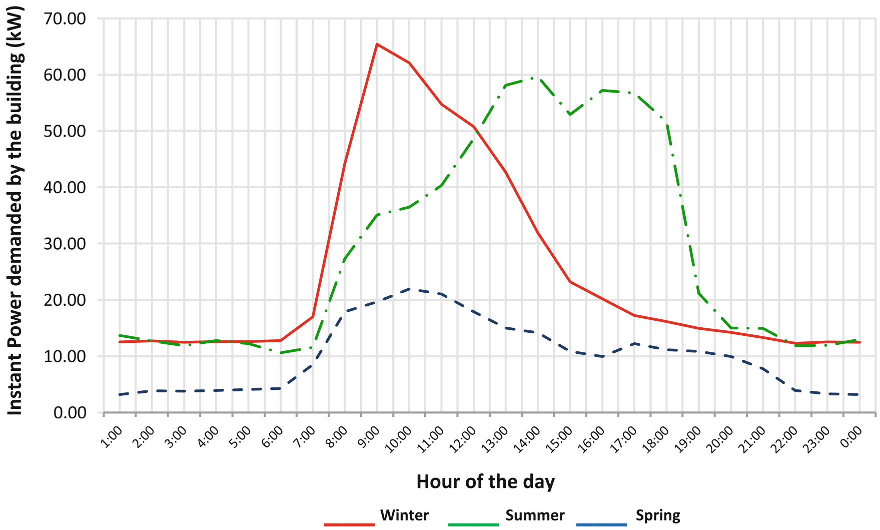

Fig. 3 Hourly power demand on working day types for various months of an administrative building of the sample

behavior of the building in different situations of the year can be observed and subsequently have influence in the determination of the design parameters of the installation. The red line corresponds to a winter situation, the green one to a summer situation and the blue one to an intermediate situation with low power demand from the HVAC system.

On the other hand, for the economic and financial analysis of the investment, a software tool that determines the hourly photovoltaic production and calculates various economic and energy parameters of the system as well as the energy balance between the photovoltaic production and the demand used.

The software tool is based in the "cell model" (Green (1982)) for the prediction of the hourly photovoltaic power production and uses the values of hourly irradiance in W/m^2 and ambient temperature provided by the PVGIS database (Joint Research Centre. Institute for Energy and Transport. Photovoltaic Geographical Information Systems (Photovoltaic). Geographical Assessment of Solar Resource and Performance of Photovoltaic Technology. http://re.jrc.ec.europa.eu/pvgis/).

With the irradiance values, and determining the influence of the temperature during the day, the maximum power current and voltage produced by the photovoltaic generator and consequently the photovoltaic production, the hourly power demand can be calculated by the following equations implemented in the calculation tool:

Short circuit current of the photovoltaic cell:

$$I_{SC} = G\left(\frac{\mathrm{W}}{\mathrm{m}^2}\right)\frac{I_{SC,std}}{1000\,\mathrm{W/m}^2} \tag{1}$$

Temperature of the photovoltaic cell:

$$T_C(^\circ\mathrm{C}) = T_a(^\circ\mathrm{C}) + \left(\frac{TONC(^\circ\mathrm{C}) - 20}{800\,\frac{\mathrm{W}}{\mathrm{m}^2}}\right) \cdot G\left(\frac{\mathrm{W}}{\mathrm{m}^2}\right) \tag{2}$$

Open circuit voltage of the photovoltaic cell:

$$V_{oc}(V) = V_{oc,std}(V) - 0.0023 \cdot (T_c(^\circ\mathrm{C}) - 25) \tag{3}$$

Normalized voltage of the photovoltaic cell:

$$v_{oc}(V) = V_{oc}(V)/V_t(V) \tag{4}$$

$$V_t(V) = 0.025(T_c(^\circ\mathrm{C}) + 273)/300 \tag{5}$$

Form factor of the ideal cell without resistance in series:

$$FF_0 = \left(\frac{v_{oc}(V) - \ln(v_{oc}(V) + 0.72)}{v_{oc}(V) + 1}\right) \tag{6}$$

The normalized resistance is defined as:

$$r_s = 1 - \left(\frac{FF_{stc}}{FF_0}\right) \tag{7}$$

The voltage and current of the cell in the point of maximum power:

$$V_{max} = V_{oc} \cdot \left[1 - \frac{b}{v_{oc}} \cdot \ln a - r_s \cdot (1 - a^{-b})\right] \tag{8}$$

$$I_{max} = I_{sc} \cdot (1 - a^{-b}) \tag{9}$$

$$a = v_{oc} + 1 - 2 \cdot v_{oc} \cdot r_s \tag{10}$$

$$b = \frac{\boldsymbol{a}}{1 + \boldsymbol{a}} \tag{11}$$

Thus, the maximum power generated by the photovoltaic cell will be:

$$\mathrm{P_{max}} = \mathrm{I_{max}} \cdot \mathrm{V_{max}} \tag{12}$$

And consequently, the maximum power produced by the photovoltaic generator will be:

$$\mathrm{P_{max}} \cdot \mathrm{G} = \mathrm{P_{max}} \cdot \mathrm{N_{mp}} \cdot \mathrm{N_{cp}} \cdot \mathrm{N_{ms}} \cdot \mathrm{N_{cs}} \tag{13}$$

where:
N_{mp} Number of modules in parallel
N_{ms} Number of modules in series
N_{cp} Number of cells in parallel inside the module
N_{cs} Number of cells in series inside the module
P_{max} is the maximum power generated by the solar photovoltaic cell

The hourly power output of the photovoltaic system is the one produced by the photovoltaic generator (the ensemble of photovoltaic modules) subtracting minus the power losses in the inverter.

The instantaneous efficiency factor of the inverter depends on the ratio between the power supplied at a given instant and the maximum power that it can produce.

This ratio, according to Lorenzo (2003), can be calculated by the following expression:

$$\eta_i = \frac{P_{salida}}{P_{entrada}} = \frac{p}{p + k_0 + k_{i1}p + k_{i2}p^2} \tag{14}$$

Where p, is the ratio between the input power of the inverter (the one that comes from the photovoltaic panels) and the nominal power that can be supplied by the inverter. The other parameters of the equation are losses factors of the inverter and depend on its quality. It has been considered that reasonable average values are:

$k_0 = 0.02$, $k_{i1} = 0.025$, $k_{i2} = 0.08$ for inverters with good efficiency factors available in the market (Jantsch et al. 1992).

With this predictive model implemented and defining a nominal power of the photovoltaic installation and the day types, the software application calculates every hour of the day the difference between the energy generated by the photovoltaic system and the energy consumed in the building. Thus the following key parameters for the sizing of the photovoltaic system can be obtained:

- The hourly power demand and power generation for the day type of each month.
- The monthly percentage of energy demanded in the building supplied by the photovoltaic installation.
- The monthly values of monetary incomes, energy demanded by the building, self-consumed energy and energy injected into the conventional power grid by the photovoltaic system.
- The financial and economic parameters: Internal return rate, net present value and payback period of the installation in the calculation conditions.
- Percentage annual coverage rate of electricity consumption by the photovoltaic system (Fig. 4).

The inputs the software needs for the calculations are:

- The nominal power of the photovoltaic installation.

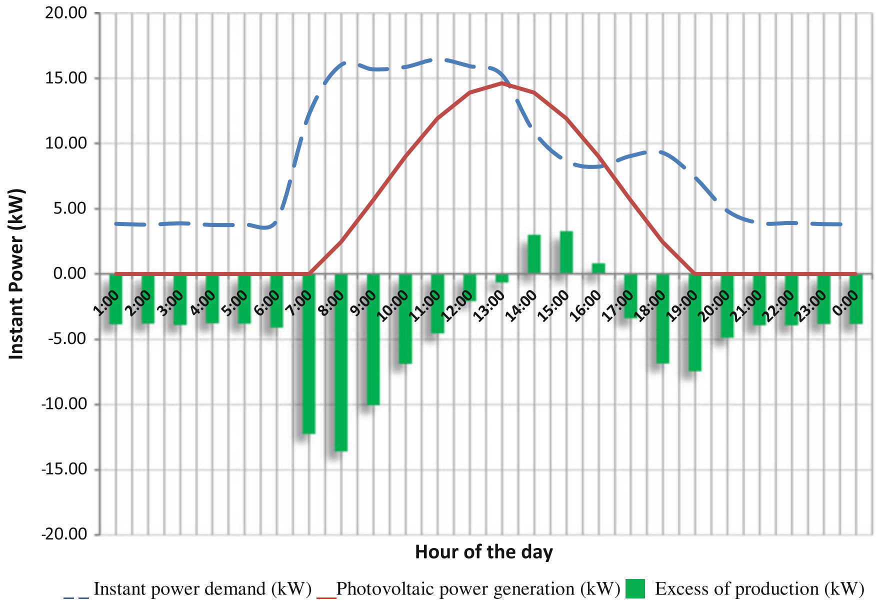

Fig. 4 Graph of photovoltaic production and building power consumption corresponding to a working day of March for one of the buildings studied

- The values of hourly irradiance in W/m^2 and hourly ambient temperature at the location of the installation.
- The hourly instant power profile for the working day types and for non working day types determined as described above.
- The electric kWh prices for each period of the contract with the company and the distribution of tariff periods of the contract.
- The values of the taxes for the photovoltaic production considered. In the study the taxes foreseen to be applied by the Government of Spain have been taken into account.

An iteration process over the values of the nominal power of the system, allows the determination of the to determine the one that optimizes the financial and energetic values of the installation.

At the end, the objective is to find by iterating over the values of the photovoltaic power the maximization of the Internal Return Rate and the Net Present Value while the payback period of the investment is minimized (Fig. 5).

Regarding the cost of installation, a value of 1.8 €/W_p plus VAT has been considered. This cost has been taken considering the study of price evolution of the technology carried out by the Institute for Energy Saving and Diversification and the Boston Consulting Group (2011) that was already mentioned in Fig. 1.

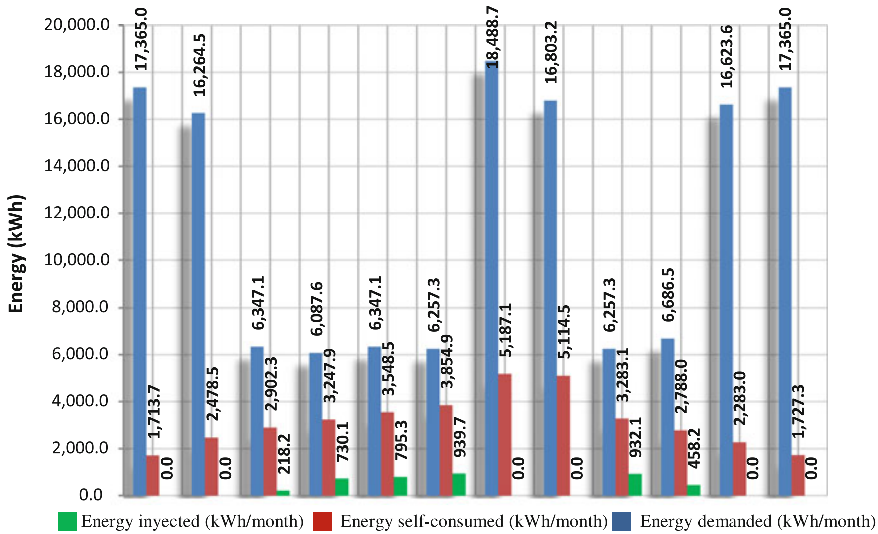

Fig. 5 Monthly energy demanded, produced and injected to the power grid every month of the year for one of the buildings studied

4 Case Studies

Depending on the type of building studied, various energetic behaviors can be observed. Administrative buildings, in working days, show a marked increase of the demanded power coinciding with the early hours of the day and the start of the activity in the building. This increase is sharper in winter season because HVAC systems of the building have to deal with higher heat loads in the first hours of the day.

In summer situations, although the increase in the power demanded by the building also occurs early, the demand peaks are shifted to the central hours of the day because in that moment the thermal loads are greater. This has some beneficial effects for the use of the photovoltaic installations since it is in the central hours of the day when the biggest photovoltaic energy generation is reached. In the intermediate situation (situations with low heat loads and consequently low power demand of the HVAC) the power demand is more stable and the shape of the graph of power vs time presents a “plateau”.

The behavior pattern is repeated on the case studies of sanitary buildings (healthcare centers) but, in these cases, there are power demands in the evenings and weekends because the activity of the building is maintained when there is an emergency service. This situation affects the improvement of the parameters of financial amortization of the installations because the building can self-consume in a bigger percentage the energy generated by the photovoltaic plant.

In relation to key financial parameters, two situations were studied: financing of the installation with 100 % of own resources or financing with 30 % with own resources and 70 % through a loan with a interest rate of 5 %.

Regarding the electric contracts of the buildings, two main types related to the kind of supply were found: low voltage electric contracts and high voltage electric contracts for the energy supply. Moreover, the cost of the kWh of electric energy depends on the period of the day where it is consumed. In all the buildings the contracts have three periods for the billing of the energy consumed and different prices depending also of the type of contract.

In summary, the types of contracts found were 3.0 A (contract with low voltage electric supply with three billing periods for the energy) and 3.1 A (contract with high voltage electric supply with three billing periods for the energy). The second one has lower prices for the energy consumed than the first one.

5 Results

Table 1 shows the great influence observed in the results in relation to the type of electrical contract for the same use of the building. Payback periods are about four years higher in buildings with 3.1 A contracts than the ones obtained in buildings with 3.0 A contracts. This is a crucial factor for the viability of the installation. Moreover, much higher financial yields are also observed in the second case.

The percentage of the energy demand of the building covered with photovoltaic energy is higher in the second case, mainly because of the minor negative impact of the possibility of excess of production in the case of buildings with 3.0 A contracts. Buildings with 3.1 A contracts must be dimensioned with smaller photovoltaic power (and consequently will have lower energy coverage) to minimize the return periods.

Table 1 Economic parameters and energy coverage rates obtained for each type of building

	Payback 30 % OR (years)	Payback 100 % OR[a] (years)	Average IRR[b](%) 30 % OR	Average IRR (%) 100 % OR
Administrative buildings 3.0 A	12.14	11.35	7.05	7.83
Administrative buildings 3.1 A	16.35	14.31	3.84	4.93
Sanitary buildings 3.0 A	11.96	11.01	7.23	8.23
Sanitary buildings 3.1 A	17.23	14.97	3.31	4.39

These results include the taxes to be established by the Spanish Government for self-consumption installations

[a]*OR* Own resources

[b]*IRR* Internal Return Rate

5.1 Sensitivity Analysis of the Results

In the following tables, the results of the sensitivity analysis carried on are shown. The parameters studied have been: the cost of the photovoltaic installations, the price of the energy contracted with the electric supply company in the building, and the amount of taxes for the photovoltaic self-consumption installation according to the proposal from the Spanish government for these installations.

In each case the aim is to determine the necessary variation of these parameters to guarantee:

- A payback period of less than ten years in all the buildings studied.
- An Internal Return Rate (IRR) of the investment over 2 % in all buildings studied.

5.1.1 Influence of the Cost of the Photovoltaic System

Tables 2 and 3 shows respectively the maximum costs of photovoltaic systems to guaratee payback periods below ten years and Internal Return Rate above 2 % in all cases.

Table 2 Maximum costs of the photovoltaic system to guarantee less than 10 years in all cases studied for the payback period

	Initial cost considered (€/W_p)	Necessary cost (€/W_p) 30 % OR	Necessary cost (€/W_p) 100 % OR
Administrative buildings 3.0 A	1.8	1.44	1.52
Administrative buildings 3.1 A	1.8	1.10	1.20
Sanitary buildings 3.0 A	1.8	1.50	1.60
Sanitary buildings 3.1 A	1.8	1.07	1.17

Table 3 Maximum costs of the photovoltaic installation to guarantee an Internal Return Rate above 2 %

	Initial cost considered (€/Wp)	Necessary cost (€/Wp) 30 % OR	Necessary cost (€/Wp) 100 % OR
Administrative buildings 3.0 A	1.8	1.25	1.35
Administrative buildings 3.1 A	1.8	0.96	1.05
Sanitary buildings 3.0 A	1.8	1.36	1.43
Sanitary buildings 3.1 A	1.8	0.93	1.03

Table 4 Increase of the prices in the electric contracts necessary to get less than 10 years for the payback period in all the buildings studied

	Initial prices considered (€/kWh) (P1–P2–P3)[a]	Necessary increase of prices 30 % OR (%)	Necessary increase of prices 100 % OR (%)
Administrative buildings 3.0 A	0.150–0.125–0.095	+14	+14
Administrative buildings 3.1 A	0.120–0.100–0.070	+48	+38
Sanitary buildings 3.0 A	0.150–0.125–0.095	+15	+9
Sanitary buildings 3.1 A	0.120–0.100–0.070	+51	+41

[a]P1–P2–P3; means the various periods of the day (period 1, period 2 and period 3) considered in the electric contract for the billing of the energy consumed in the building

Table 5 Increase of the prices in the electric contracts necessary to guarantee an Internal Return Rate above 2 % in all the cases studied

	Initial prices considered (€/kWh) (P1–P2–P3)	Necessary increase of prices 30 % OR (%)	Necessary increase of prices 100 % OR (%)
Administrative buildings 3.0 A	0.150–0.125–0.095	+33	+25
Administrative buildings 3.1 A	0.120–0.100–0.070	+66	+53
Sanitary buildings 3.0 A	0.150–0.125–0.095	+28	+19
Sanitary buildings 3.1 A	0.120–0.100–0.070	+69	+56

5.1.2 Influence of the Contract Price of Electricity Consumed in the Building from the Conventional Power Grid

The results of Tables 4 and 5 are obtained by keeping constant the taxes initially considered and the cost of the photovoltaic system of 1.8 €/W_p.

5.1.3 Influence of the Value of the Taxes for Energy Backup with the Conventional Power Grid

The results of Tables 6 and 7 are obtained by keeping constant the cost of photovoltaic systems 1.8 €/W_p and the costs of the electricity consumed by conventional power grids.

Table 6 Necessary decrease of taxes to guarantee a payback period of 10 years in all the buildings studied

	Initial value of the taxes considered (€/kWh) (P1–P2–P3)	Necessary decrease of the taxes 30 % OR (%)	Necessary decrease of the taxes 100 % OR (%)
Administrative buildings 3.0 A	0.040596–0.025953–0.009265	–70	–50
Administrative buildings 3.1 A	0.032159–0.024332–0.012184	–181	–144
Sanitary buildings 3.0 A	0.040596–0.025953–0.009265	–55	–34
Sanitary buildings 3.1 A	0.032159–0.024332–0.012184	–188	–50

Table 7 Necessary decrease of taxes to guarantee an IRR above 2 % (calculated for 10 years) in all the buildings studied

	Initial value of the taxes considered (€/kWh) (P1–P2–P3)	Necessary decrease of the taxes 30 % OR (%)	Necessary decrease of the taxes 100 % OR (%)
Administrative buildings 3.0 A	0.040596–0.025953–0.009265	–123	–92
Administrative buildings 3.1 A	0.032159–0.024332–0.012184	–250	–200
Sanitary buildings 3.0 A	0.040596–0.025953–0.009265	–104	–77
Sanitary buildings 3.1 A	0.032159–0.024332–0.012184	–256	–206

6 Conclusions

Two factors, the type of use of the building and the electrical contract with the company that supplies the energy to the building from the conventional power grid, have a strong influence in the results of the case studies.

The first factor has an influence in the hourly distribution of the energy demand during the day and therefore, a greater or lesser fitting of the photovoltaic energy generation with the energy demand of the building.

The second one has an influence in the price of electricity consumed in the building (and therefore on the economic performance obtained from the photovoltaic system because part of that power will be replaced by the photovoltaic energy generated) as well as in the daily distribution of these costs and the amount of taxes to be considered under the new legislation proposed by the Ministry of Industry and Energy of Spain on this matter (Spanish Ministry of Industry and Energy (2013) Draft of Royal Decree to regulate administrative, economic and technical conditions for supply of electrical energy with self-consumption and production with self-consumption (July 18)).

Therefore, in relation to the economic viability of photovoltaic systems for self-consumption, several considerations must be taken into account:

- The Photovoltaic production is concentrated in the middle hours of the day, the most suitable profiles of electrical demand of the buildings should be those that have high and stable energy demands in that hours of the day to make profitable the investment in the installation. Whenever, it would be interesting to study strategies for the movement of energy loads to those hours of the day.
- The excesses of photovoltaic energy production is sold to the conventional electricity grid at market price (about 5 c €/kWh average price in Spain) whereas if the energy is self-consumed in the building, its value is the cost of electricity replaced and therefore a have a higher value (12–15c €/kWh).
- The sizing of the photovoltaic power installed should consider a compromise between minimizing the injection of energy into the conventional power grid and maximizing the NPV (Net Present Value) of the Investment. The goal is to minimize the payback period of the investment and maximize the IRR (Internal Rate of Return).
- With this procedure, photovoltaic coverage between 17 and 28 % in administrative buildings and 23 and 35 % in health centers were obtained in the cases studied.
- According to the results, the best electric contract for the buildings in order to make profitable the investments should be 3.0 A contract (low voltage supply contracts with three points and followed), this is because the difference between the price of the energy from the power grid and the taxes per kWh is higher than in other types of contracts. The electrical contract, if taxes are considered, is decisive in establishing the viability of the installation. Buildings with the same use shall clearly have better profitability for the same installed power and economic performance if the contract is 3.0 A than if it is 3.1 A. The consideration of these taxes difficult the viability of the installations so that in the present situation in Spain, without taxes, clearly better economic results would be obtained. However, taxes have been taken into account in the study because although it is not in force in Spain nowadays it is foreseeable in the future.
- Although administrative buildings and healthcare centers are not those with the best energy demands profiles for making the photovoltaic installation profitable because there have a significant number of hours in which they have very low electric power demands (evenings, holidays and weekends mainly), those buildings which have 3.0 A contracts obtain acceptable economic results in absence of taxes for the self-consumption. In any case, high energy coverage for the optimum photovoltaic power (at around 28 % in the case of administrative and 35 % for health centers) is obtained.

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Analysis and Comparison of Energy Saving Measures Through Marginal Abatement Cost Curves

R. Fresco Contreras

Abstract In the European Union, the building sector uses the 40 % of the total final energy consumption. This, together with the commitment to achieve the Kyoto Protocol levels, in terms of energy consumption and emissions of greenhouse gases, has led to changes in the legislation of the sector to get lower energy demand in buildings. In Spain, from 1st June 2013, it is required to make the energy performance certificate available to buyers and/or users every time buildings or units thereof are built, reformed, rehabilitated, sold or rented. For existing buildings, the certificate will include a proposal of a series of measures to improve the energy rating, and the impact of each measure will be indicated. The aim of this work is to study, in detail, the results obtained after implementing the various measures for energy rehabilitation in existing residential buildings, through the creation of marginal abatement cost curves, showing the results in savings obtained in relation to the cost of implementing the measure.

Keywords Energy certification for existing buildings · CO_2 emissions · Primary energy consumption · Final energy consumption · Marginal cost curves

1 Introduction

The building sector is responsible for 30 % of CO_2 emissions approximately, and between 30 to 40 % of the total energy demand (Erlandsson and Borg 2003). Thus, for example, the 40 % of the energy consumption in the European Union comes from the building sector (European Union 2010). Due to this, research has taken place in order to reduce the energy consumption effects in the climate coming from buildings because of the big economical potential of energy saving and the

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reduction of existing emissions (Report of Intergovernmental Panel on Climate Change [IPCC] 2007).

When it comes to select building energy retrofit measures (ERM), it is very important to take into account the initial investment and the operational cost according to the measure that has been taken. If only the operational cost is minimized, a large initial investment will be necessary (Jacob 2006). A way to solve this problem is through the calculation of marginal abatement cost of each measure, which can be visualized well arranged in a graphical representation, making an easier selection (Banaitiene et al. 2008). These graphical representations are called marginal abatement cost curves (MACC). Since their creation (Stanford University 1993), these curves have had an important role against the Climate Change (Kesicki 2013) because of they provide simple graphics that combine economic data with climate change reduction. There is a wide variety of researches where MACCs are defined as a tool to assist policy-making against global warming (McKinsey and Company 2008; Government of Chile 2009).

In this way, MACCs can be divided into model-based and expert-based curves (Kesicki 2010). This paper is based on the residential sector and microeconomic criteria, therefore the MACCs are the expert-based ones.

According to the aim of building refurbishment, technicians may search for the best relation between marginal cost and benefit taking into account different criteria: economical, CO_2 emission reduction, primary and/or final energy consumption reduction. Furthermore, it is very important to get to know the classification of measures in terms of effectiveness, and not only consider which the best one is (Wang et al. 2005). These curves should also give information about each ERM to facilitate it identification (Junghans 2013).

This research pursues to define an optimization method in order to classify the ERM which can be applied to existing buildings based on the potential savings in energy consumption and reduce CO_2 emissions, taking as reference a specific methodology designed in order to be applied in Spain (Economics for Energy 2011). In order to calculate the impact of each measure, CE3X v1.1 had been used. It is acknowledged as an official procedure for energy certification for existing buildings in Spain (Institution for Diversity and Energy Saving [IDAE] 2012).

In this study area, energy optimization is defined as the procedure to find the measures with the highest economical potential of emission reduction and/or energy consumption reduction according to several variables (Machairas et al. 2014). The criterion used for the ERM assessment has been the life cycle cost of each of them, including execution, energy consumption and maintenance costs.

2 Objective

The main objective of this research is to develop a comparison methodology of energy saving measures which are based on a long-term analysis.

3 Methodology

This study presents a methodology to create MACC based on the analysis of life cycle cost of ERM which take place in existing buildings.

Thus, the progress of this research has been divided into the following steps:

1. Definition of MACC creation methodology.
2. Application to real cases.
3. Results analysis.

3.1 Methodology's Definition for the Creation of MACC

MACC are defined in a graph which indicates the marginal abatement cost (MAC) which is associated with the potential of emission or energy consumption reduction (kgCO_2/year or kWh/year) (Kesicki and Strachan 2011). The MAC is usually represented either by €/kgCO_2 or €/kWh saved. As it was mentioned above in the Introduction, and it is shown in Fig. 1, expert-based MACCs are used. Figure 1 contrasts the marginal abatement cost of each measure on y-axis, against the potential of emission reduction on x-axis.

Traditionally, these graphs have been used as helping tools for decision-making on environmental policies (Kuik et al. 2009). The innovation which comprises this research is adapting this model to be applied to existing buildings in an individualized way. In order to calculate MACC, this paper is based on the methodology developed in the document "Economical potential of energy demand reduction in Spain" (Economics for Energy 2011), where Eq. (1) is defined this way:

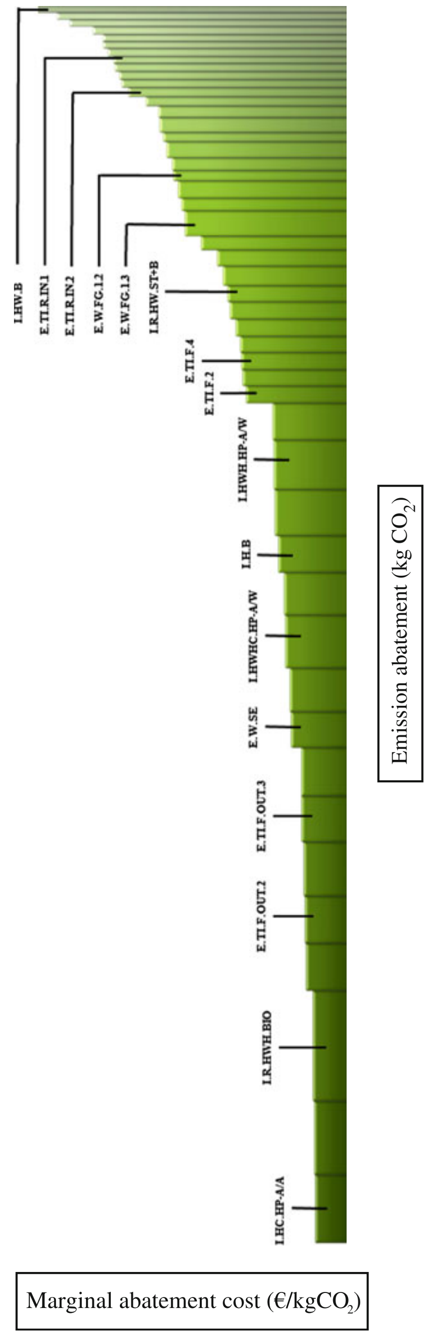
$$CMLP = C_{INV} * \frac{i * (1+i)^n}{(1+i)^n - 1} + Opex \quad (1)$$

where:

- Cinv: the necessary initial investment for each ERM (€)
- i: inflation index
- n: number of years in an useful life
- Opex: life cycle cost according to each measure, which includes: maintenance, operation and energy consumption costs

First part Eq. (1) represents the necessary initial investment so as to establish a specific technology, which is equally distributed in the life cycle.

Fig. 1 Example of expert-based MACC



To define life cycle cost, the following Eq. (2) is developed as a result of the research which has been undertaken. Hence:

$$Opex = \frac{(\alpha * \beta + \gamma) * \frac{(1+i)^n - 1}{i * (1+i)^n}}{n} \quad (2)$$

where:

- α: energy consumption of the new technology per year, where appropriate (KWh/year)
- β: cost of energy consumption which has been used (€/KWh in the case of electrical energy; €/kg in the case of biomass)
- γ: estimated percentage of maintenance costs per year
- i: inflation index
- n: number of years in a productive life

The calculation system has been implemented in a tool based on Microsoft Excel.

On the one hand, all energy data related to emissions saving and primary and final energy consumption have been obtained by the use of CEX3 v1.1.

On the other hand, an exhaustive search of the possible ERM was done. In total, 48 measures were listed (passive and active ERM). In this way, each measure has been given its own code in order to identify them in the MACC.

A simulation for each measure related to thermal insulation (Table 1) has been done, taking into account different thermal conductivity values. In Table 2 is shown a classification example (similar to the left cases).

For the replacement of windows different materials have been several types of glasses and frames, as Tables 3, 4, and 5 show.

Physical properties of materials have been taken from the "Catalogue of Building Elements" in the "Building Technical Code" (Eduardo Torroja Institute 2010). Besides, the cost of measures is calculated according to all information specified in the "Bank of Construction Costs in Andalusia" (Andalusia Regional Government 2013).

Table 1 Passive ERM

		Code
Thermal insulation	Facade (outside)	E.TI.F.OUT.
	Facade (inside)	E.TI.F.IN.
	Roof (outside)	E.TI.R.OUT.
	Roof (inside)	E.TI.R.IN.
	Floor	E.TI.F.
Windows	Glasses	E.W.G.
	Frame and glasses	E.W.FG.
	Tightness	E.W.T.
	Double window	E.W.DW.
	Shade elements	E.W.SE.

Table 2 Passive ERM subcategories: roof outside thermal insulation

	Material	Thermal conductivity (W/mK)	Code
Roof (outside thermal insulation materials)	EPS	0.037	E.TI.R.OUT.1
	RW	0.031	E.TI.R.OUT.2
	XPS	0.038	E.TI.R.OUT.3
	PUR	0.035	E.TI.R.OUT.4

EPS expanded polystyrene, *RW* rock wool, *PUR* projected polyurethane, *XPS* extruded polystyrene

Table 3 Passive ERM subcategories: windows

	Element	Glass type/frame and glass type	Code
Windows	Glass	Double glazing	E.W.G.1
		Low-emissivity glass	E.W.G.2
		Solar control glass	E.W.G.3
	Frame and glass	Metal (TB) + double glazing	E.W.FG.1.1
		Metal (TB) + low-emissivity glass	E.W.FG.1.2
		Metal (TB) + solar control glass	E.W.FG.1.3
		PVC + double glazing	E.W.FG.2.1
		PVC + low-emissivity glass	E.W.FG.2.2
		PVC + solar control glass	E.W.FG.2.3
		Wood + double glazing	E.W.FG.3.1
		Wood + low-emissivity glass	E.W.FG.3.2
		Wood + solar control glass	E.W.FG.3.3
	Tightness		E.W.T
	Double window		E.W.DW
	Shade element		E.W.SE

TB thermal break, *PVC* polyvinyl-chloride

Table 4 Passive ERM subcategories: thermal properties of glass

Type	Thickness (mm)	U-Value (W/m^2K)	Solar factor
Double glazing	4 + 6 + 4	3.30	0.75
Low-emissivity glass	4 + 6 + 4	2.70	0.70
Solar control glass	4 + 6 + 4	2.40	0.30

Table 5 Passive ERM subcategories: thermal properties of frames

Material	U-Value (W/m^2K)	Absorptivity
Metal (with TB)	3.30	0.55
PVC	2.70	0.55
Wood	2.40	0.55

TB thermal break, *PVC* polyvinyl-chloride

Table 6 Active ERM

Production of			Code
HW	Conventional boiler		I.HW.B.
Heating	Conventional boiler		I.H.B
	Condensation boiler		I.H.CB
	Low temperature boiler		I.H.LTB
HW and heating	Conventional boiler		I.HWH.B
	Condensation boiler		I.HWH.CB
	Low temperature boiler		I.HWH.LTB
	Heat pump air/water		I.HWH. HP-A/W
Heating and cooling	Heat pump air/air		I.HC.HP-A/A
	Heat pump air/water		I.HC. HP-A/W
HW, heating and cooling	Heat pump air/water		I.HWHC. HP-A/W
Renewables	HW	Solar thermal energy + conventional boiler	I.R.HW. ST + B
		Biomass boiler	I.R.HW.BIO
	HW and heating	Solar thermal energy + condensation boiler	I.R.HWH. ST + CB
		Biomass boiler	I.R.HWH. BIO

In the same way, active measures has been selected to improve hot water (HW), heating and cooling production process (as Table 6 shows).

96 simulations have taken place because of the methodology has been applied to two individual cases.

3.2 *Summary of the Methodology Established*

Figure 2 shows the calculation and comparison process developed in the present study, where LCMC represent the life cycle marginal cost of each ERM.

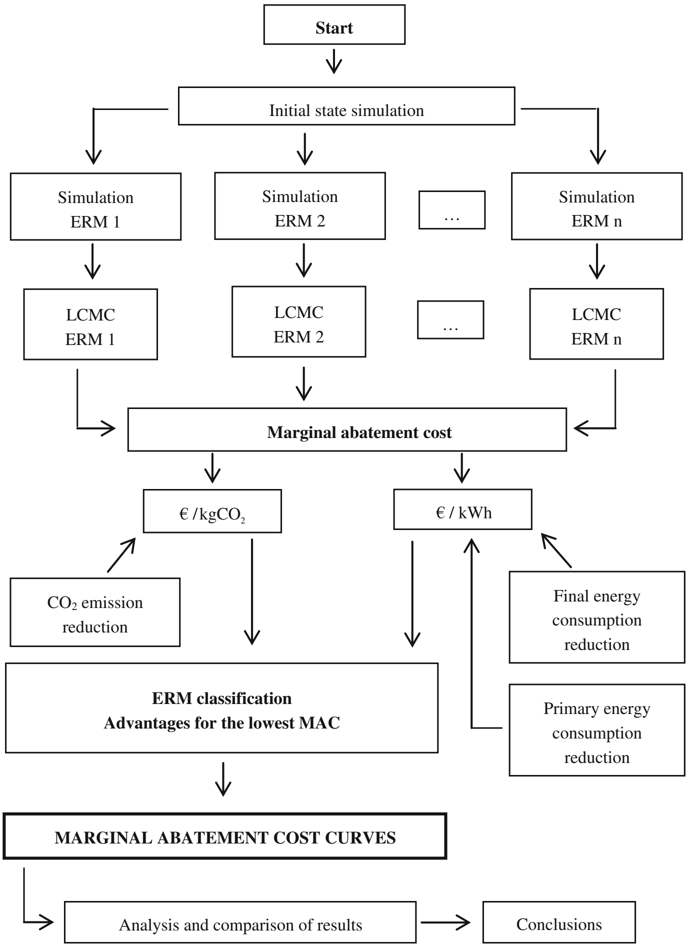


Fig. 2 Diagram of ERM calculation and comparison

4 Cases of Study

To prove the results obtained from the tool's use, two real buildings (multi-family and single family building) which were located in different places from Seville (one in the city and the other one in the sierra) were simulated. Thus, an exhaustive collecting data of buildings was done with the aim of adjusting results to the reality.

The multi-family building comprises three floors (including ground floor), being the ground floor used for commercial purposes and the first and the second ones as residence. The gross floor area of the building is 371.0 m^2. It comprises two main facades, whose orientations are east and southeast respectively. It also has two patios. It has got several windows and balconies in every facade, having approximately the 20 % of the opaque surface. Windows have a metal frame with no thermal break and simple glass (frame and glass U-value: 5.70 W/m^{2}K; solar factor: 0.82). U-value is 1.03 W/m^{2}K for the facade, 1.86 W/m^{2}K for the roof and 2.56 W/m^{2}K for the floor which divides ground floor from first floor. For heating, an electrical heater is localized in each room, except in the sitting-room, where there has been installed a heat pump with 200 % heating and 150 % cooling seasonal energy efficiency ratio. To produce HW, each house has a conventional boiler, with 85 % of combustion efficiency.

The single family unit comprises two floors (including the ground floor), using the whole for residential purposes. The gross floor area of the house is 105.0 m^2. Its main facades have orientation to north and southwest respectively, with an area of 30.25 m^2 each. Each facades has got windows with the same thermal properties which were described before for the multi-family building (22 % of opaque surface). The U-value is 1.31 W/m^{2}K for facades and 1.28 W/m^{2}K for roofs. In the two main rooms and dining-room a heat pump is installed. The heating and cooling seasonal energy efficiency ratio are 201 and 157 % respectively. It also has a conventional boiler to hot water production, with 85 % of combustion efficiency.

5 Results

Using the process of calculation, 3 MACC has been obtained for each simulated building, similar to the one which is shown on Fig. 1, attached to a table where all properties of each ERM are indicated. MACCs are referred to energy saving (primary and final energy) and CO_2 emission savings.

As an example, Table 7 shows the reduction of CO_2 emissions for the multi-familiar building. It shows the ERM classified according to the marginal abatement cost (€/KgCO_2) from the least to the highest.

Table 7 ERM results according to the CO_2 emission saving; multi-family housing unit

ERM	Marginal abatement cost (€/kgCO_2)	Emission saving potential (kgCO_2/year)	Economical saving potential (€/year)	Return period (years)	Is it going back in the useful life?
I.HC.HP-A/A	0.43	11,112.84	1776.82	7.45	Yes
I.R.HWH. ST + CB	0.43	12,135.67	3130.43	10.84	Yes
I.R.HWH.BIO	0.45	18,079.10	2595.96	26.36	No
E.TI.F.OUT.1	0.54	7602.07	1624.87	15.49	Yes
E.TI.F.OUT.2	0.56	7740.29	1651.80	18.16	Yes
I.HWH.CB	0.57	8846.04	2287.67	9.87	Yes
E.TI.F.OUT.3	0.60	7602.07	1621.70	21.61	Yes
I.HWH.B	0.60	7906.15	2221.09	7.94	Yes
E.W.SE	0.73	5888.15	1255.69	9.25	Yes

(continued)

Table 7 (continued)

ERM	Marginal abatement cost (€/kgCO_2)	Emission saving potential (kgCO_2/year)	Economical saving potential (€/year)	Return period (years)	Is it going back in the useful life?
I.H.CB	0.75	7187.41	1536.14	12.54	Yes
I.HWHC.HP-A/W	0.80	8735.47	1777.64	24.80	No
I.HWH.LTB	0.83	6828.04	1746.53	14.28	Yes
I.H.B	0.90	6026.37	1285.79	13.71	Yes
I.HC.HP-A/W	0.95	7602.07	1028.95	37.70	No
I.HWH.HP-A/W	0.95	8188.40	1586.71	33.23	No
I.H.LTB	0.97	5971.08	1274.70	17.17	Yes
E.TI.F.2	1.31	2819.68	604.47	17.02	Yes
E.TI.F.1	1.37	2709.10	578.33	17.42	Yes
E.TI.F.4	1.38	2736.74	586.25	21.23	Yes
E.TI.F.3	1.40	2681.46	574.37	19.41	Yes
E.W.DW	1.44	2874.96	611.60	37.03	Yes
E.W.FG.2.3	1.52	2736.74	582.29	38.92	Yes
I.R.HW.ST + B	1.56	3096.12	1301.37	7.12	Yes
E.W.FG.2.2	1.61	2626.17	562.48	43.25	Yes
E.W.FG.2.1	1.69	2405.02	511.78	37.08	Yes
I.R.HW.BIO	1.90	4063.65	1120.01	42.11	No
E.W.FG.1.3	2.11	2128.58	453.95	64.94	No
E.W.FG.3.3	2.15	2736.74	582.29	59.70	No
E.TI.F.IN.2	2.20	1713.92	369.18	24.51	Yes
E.W.FG.1.2	2.26	2018.00	431.77	72.13	No
E.W.FG.3.2	2.27	2626.17	562.48	64.76	No
E.TI.F.IN.4	2.34	1680.99	349.37	37.46	Yes
E.W.FG.3.1	2.39	2405.02	511.78	60.72	No
E.W.FG.1.1	2.44	1796.85	381.86	67.55	No
E.TI.F.IN.3	2.44	1575.70	335.91	31.73	Yes
E.W.G.3	2.61	1465.13	310.56	13.49	Yes
E.TI.R.IN.2	2.84	1299.26	279.66	19.88	Yes
E.W.G.2	2.92	1326.91	285.20	18.37	Yes
E.TI.R.OUT.2	2.96	1299.26	279.66	34.28	Yes
E.TI.R.IN.4	3.01	1243.97	263.81	25.55	Yes
E.TI.R.IN.1	3.04	1216.33	257.48	20.54	Yes
E.TI.R.IN.3	3.11	1188.69	254.31	21.29	Yes
E.TI.R.OUT.1	3.16	1216.33	257.48	36.21	Yes
E.TI.R.OUT.4	3.16	1243.97	263.81	44.80	Yes
E.TI.R.OUT.3	3.29	1188.69	254.31	44.00	Yes
E.W.G.1	3.60	1050.47	221.83	8.30	Yes
E.TI.F.IN.1	3.76	1003.35	339.87	25.43	Yes
I.HW.B	10.36	497.59	212.47	11.62	Yes

Table 8 Outline of results: multi-family housing unit

	CO_2 emission savings	Primary energy savings	Final energy savings
Favourable measures	I.HC.HP-A/A	I.HC.HP-A/A	I.R.HWH.BIO
	I.R.HWH.ST + CB	I.R.HWH.ST + CB	I.HC.HP-A/A
	I.R.HWH.BIO	E.TI.F.OUT.1	I.R.HWH. ST + CB
Unfavourable measures	E.W.G.1	E.TI.R.OUT.3	E.TI.R.OUT.3
	E.TI.F.IN.1	E.W.G.1	E.W.G.1
	I.HW.B	I.HW.B	I.HW.B

6 Conclusions

Before selecting the ERMs according to the MACC, it is recommended to prove that those measures produce the refund of the initial investment in its period of productive life. Otherwise, this will not be considered profitable.

In both cases of study, most of favourable measures are the ones which implement energy coming from renewable sources. Furthermore, it is proved that the three ideal measures have the same system in most of cases. It also happens with the most unfavourable ones (but profitable) (Table 8).

It is very important to emphasize that this methodology does not give priority to passive measures. However, it gives preference to measures in order to replace the thermal production system.

The measures related to outside facade thermal insulation are better classified than the inside ones because of they produce better benefits, although their cost to set up is higher, due to a larger reduction of the energy demand produced by the removal of the thermal bridges which exist in facades.

In conclusion, the methodology for the creation of MACC is considered valid as a tool of selection of ERM for existing buildings. However, it would be a good recommendation to do other comparisons with other economic criteria, such as the Net Present Value, which guarantee the results are optimum.

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A Comparison Between Spanish and Australian Building Energy Efficiency Codes. A Case Study

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Abstract The main aim of this study is to compare the requirements established by Spanish and Australian Building Codes in energy efficiency terms through a case study. First the BCA (Building Code of Australia) was analyzed in detail by studying its structure and finding a correlation of the sections with the Spanish Building Code (CTE; Código Técnico de la Edificación) in Spain. Then the contents in both regulations were identified, as were the building classification, usages and climate zones by climate severity defined for summer and winter using accumulated global radiation and degree per day average. Other factors, such as solar heat gain coefficient, helped develop and facilitate the comparison between both Building Codes. To illustrate the comparison, a detached house was analyzed by implementing the energy requirements for both Building Codes, and by providing construction solutions through natural insulation. The points that presented de most notable differences were identified, as well as the topics with more restrictive regulation notable differences, whose regulation is more restrictive in each aspect. Finally, a programmed software, capable of automatically determining these data, was developed to facilitate the comparison for any other case study.

Keywords Building code · Energy efficiency · Climate zone · Case study

1 Introduction

One of today's worldwide concerns involves efforts that aim to reduce energy consumption and CO_2 emissions (Rodríguez-Soria et al. 2014). The building sector is responsible for approximately 40 % of energy consumption and greenhouse gas emissions (CEC 2012), and two thirds of these emissions result from residential

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buildings (Sharma et al. 2011), which have the highest potential for energy savings (Martínez de Alegría et al. 2009).

Many energy efficiency-related regulations have been enforced in the last few decades. However, requirements vastly vary from one country to another. Energy efficiency is defined by the energy yield of facilities and by envelope energy loss. Energy loss depends on the morphology and characteristics of buildings, which are conditioned mainly by thermal envelope transmittance, including walls, floors, roofs and windows.

As no harmonization exists in the building energy efficiency requirements mandated by different countries, the interest of this paper lies in presenting variation in requirements between two very different countries, with some similarities among some of their climate zones: Spain and Australia.

This paper focuses on thermal envelope requirements, and also discusses the causes of the divergences in requirements and their degrees of disparity. The results of the study can help find strengths and weaknesses in regulations, and allow improvements to be made in the technologies and construction systems used.

2 Objectives

The main objective of this study is to compare the requirements established by Spanish and Australian Building Codes in energy efficiency terms by focusing on the thermal envelope of buildings, which is the most significant energy performance element.

The specific objectives of this study are to make a comparison between the structure of both regulations, and of the building classification, usages and climate zones.

3 Comparison Between Australian Building Codes and the Spanish Equivalent, Código Técnico de la Edificación

In Spain, energy efficiency is regulated by the Código Técnico de la Edificación (CTE) in section "CTE DB HE Ahorro de Energía" (CTE 2006), and is regulated in Australia by the National Construction Code (NCC).

The NCC comprises the Australian Building Code (BCA 2012), published in "Volume One" for building Classes 2–9, and in "Volume Two" for building Classes 1 and 10, and the Plumbing Code of Australia (PCA) in "Volume Three".

Table 1 Example of building classes defined by BCA and CTE

BCA 2012			CTE-DB-SI
Class subclass		Description	Category assigned
1	Class 1a	A single dwelling: a detached house or one or more attached dwellings	Residential (housing)
	Class 1b	A boarding house, guest house or hostel not exceeding 300 m^2 and no more than 12 residents	Residential (public)
10	Class 10a	A non-habitable building: a private garage, carport, shed, or the like	Car park
	Class 10b	A structure: a fence, mast, antenna, either retaining or free-standing wall, a swimming pool, or the like	Not provided

3.1 Building Usage Classification

In Spain and Australia, buildings are classified according to their usage. The most common typology in Australia is a one-story single dwelling, which corresponds to Class 1. Commercial, educational, administrative buildings, hospitals, among others, are included in Classes 2–9, and detached garages or additional structures are included in Class 10.

In Spain, usages are presented in section "CTE-DB-SI Seguridad en caso de incendio". Table 1 shows some examples of the correlation found between building usages in both countries.

3.2 Structure of Documents

Both regulations present some similarities as far as structure is concerned. Reviewing the energy efficiency section, a connection was made between the BCA and Spanish legislation in general (including the CTE and others). Table 2 offers a brief example.

The main difference found between Australian and Spanish legislation is that the BCA comprises all the aspects involved in buildings in only one regulation, while Spanish legislation is a compendium of several documents, each devoted to a different topic.

3.3 Climate Zones

Both countries have several climate zones depending on geographical points and altitudes above sea level. Both regulations separate their territories into different

Table 2 Example of similarities in the structure of BCA and CTE energy efficiency sections

BCA 2012 (Volume II)	CTE 2006 (and other Spanish legislation)
3.12 Energy efficiency	CTE-DB-HE2: regulations on thermal installations in buildings (RITE 2007)
3.12.0 Application of Part 3.12	
3.12.0.1 Heating and cooling loads	
3.12.1 Building fabric	CTE-DB-HE1-19: required characteristics for external walls and interior partitions of the thermal envelope
3.12.1 Application	
3.12.1.1 Building fabric thermal insulation	
3.12.1.2 Roofs	CTE-DB-SE-F-35: Type of walls. CTE-DB-SE-C: Foundations
3. 12.1.3 Roof lights	
3.12.1.4 External walls	
3.12.1.5 Floors	
3.12.1.6 Attached class 10a buildings	
3.12.2 External glazing	CTE DB-HE1-43: Windows and roof lights
3.12.2 Application	
3.12.2.1 External glazing	
3.12.2.2 Shading	

climate zones. So in order to compare requirements, first zones have to be linked (see Fig. 1 and Table 3).

It is worth noting that although Spain and Australia are located in the Northern Hemisphere and the Southern Hemisphere, respectively, climates present many similarities and most can be matched to be compared.

In a preliminary study, zones can be matched as shown in Table 3.

However for more precise determinations, CTE-DB HE Annex D establishes a method to obtain the relative climate zone of any place in the world based on solar irradiation and the maximum and minimum temperatures in degrees. A practical application of this methodology is provided in the case study of this paper.

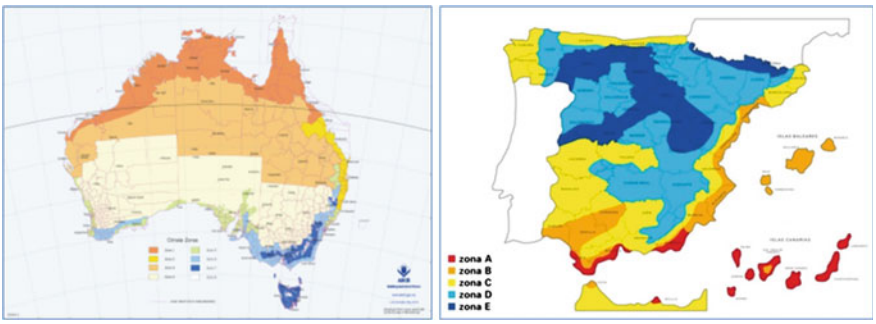


Fig. 1 Climate zones defined by codes BCA (2012) and CTE (2006)

Table 3 Climate zones

Australia	Spain
Zone 1: Equatorial and tropical	Zone A: Subtropical
Zone 2: Subtropical	
Zone 3: Northern dessert and grassland	
Zone 4: Southern dessert and grassland	
Zone 5: Subtropical	
Zone 6: Temperate (low altitude)	Zone B: Mediterranean or Zone D: Mediterranean-Continental
Zone 7: Temperate (high altitude)	Zone C: Oceanic
Zone 8: Alpine	Zone E: Highland

4 Case Study: Masonry Veneer House

In order to compare the thermal requirements mandated by Spanish and Australian legislation, a case study was conducted, on a real building where both legislation requirements were implemented. This case study allowed to compare requirements and to identify which regulations were more restrictive.

4.1 Case Study Description

The case study consists of a 3-bedroom masonry veneer house located in Morwell, the State of Victoria, Australia. It has cavity masonry walls in the lounge, and the wall between the house and the garage is a stud wall.

Building usage corresponds to Class 1a, so Volume II should apply. The location of Morwell in Australia is shown in Fig. 2.

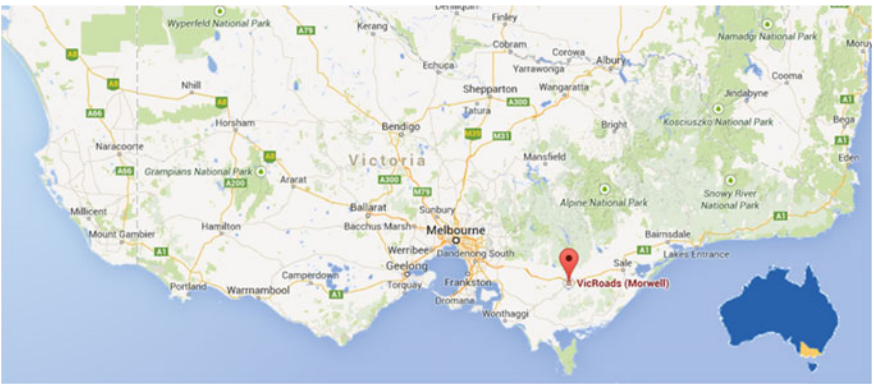


Fig. 2 Location of Morwell. *Source* Google Maps (2014)

The house design includes a concrete slab-on-ground with a conventional pitched tiled roof and a roof upper surface solar absorbance value of more than 0.6 and a flat ceiling.

The house has three ceiling fans and four downlights built in the ceiling. An in-slab heating system is installed under the bathroom. It has a thermostat and a timer, and the power load is 120 Wh/m^2.

A reverse-cycle air-conditioning system is installed in the rest of the house (not the garage). The proposed lighting system totals 500 W for all the house and 60 W for the garage. There are no lighting controls and the supply water heater is a 5-star gas unit. Star gas units were established in Australia as energy-rating labels for many electric appliances, as were water heaters or ducted heaters. The intention is to reduce energy consumption and to help consumers choose the most efficient installations to save utilities costs (Australian Government 2014).

The floor plan and a section of the house are presented in Figs. 3 and 4.

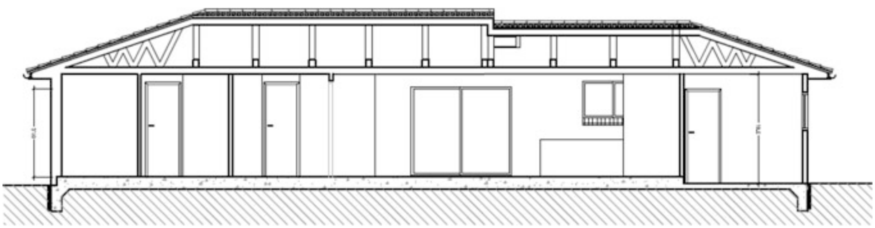


Fig. 3 Section of the masonry veneer house

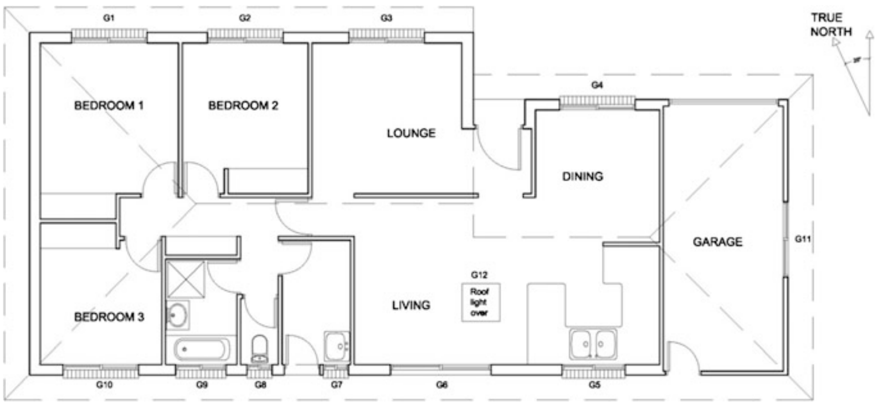


Fig. 4 Floor plan of the masonry veneer house

4.2 Determining Spanish Climate Zones

Morwell is located in climate zone 6 (temperate—low altitude) according to Australian climate zones. In order to implement Spanish regulation into the building, the matched climate zone in Spain should be determined. According to the method described in the CTE, Morwell matches zone D1, and one of the Spanish cities included in this zone is Pamplona. Figure 5 shows the methodology to calculate the relative climate zone according to degree days (GD) and solar irradiation in the location.

As presented in Fig. 5, firstly the temperatures in Morwell through every month of the year were identified according to official meteorological data, and the solar radiation which depends on the latitude of the location was also analyzed. Both data were introduced into the mathematical expressions in Fig. 5, which with the terms expressed as follows:

- SCI: climate severity in winter
- SCV: climate severity in summer
- GD: Degree Days

The degree per day average was also calculated and introduced into the expressions for summer and winter. Finally, the SCI and SCV values were obtained, which were checked in CTE-DB HE (see Table D.2a-Severidad climática de invierno and Table D.2b-Severidad climática de verano in Fig. 5).

Morwell corresponds to climate zone D1 in Spain, in which the city of Pamplona was selected (Fig. 6).

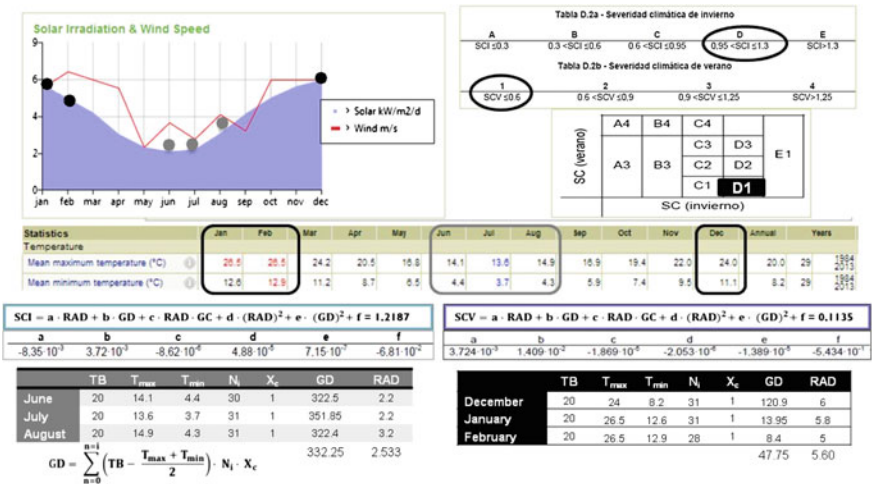


Fig. 5 Determining the relative climate zone for any Spanish city

Capital de provincia	Capital	Altura de referencia (m)	Desnivel entre la localidad y la capital de su provincia (m)				
			≥200 <400	≥400 <600	≥600 <800	≥800 <1000	≥1000
Albacete	D3	677	D2	E1	E1	E1	E1
Alicante	B4	7	C3	C1	D1	D1	E1
Almeria	A4	0	B3	B3	C1	C1	D1
Ávila	E1	1054	E1	E1	E1	E1	E1
Badajoz	C4	168	C3	D1	D1	E1	E1
Barcelona	C2	1	C1	D1	D1	E1	E1
Bilbao	C1	214	D1	D1	E1	E1	E1
Burgos	E1	861	E1	E1	E1	E1	E1
Palencia	D1	722	E1	E1	E1	E1	E1
Palma de Mallorca	B3	1	B3	C1	C1	D1	D1
Palmas de Gran Canaria (las)	A3	114	A3	A3	A3	B3	B3
Pamplona	D1	456	E1	E1	E1	E1	E1
Pontevedra	C1	77	C1	D1	D1	E1	E1
Salamanca	D2	770	E1	E1	E1	E1	E1

Fig. 6 Climate zones in Spain according to the Spanish Building Code (CTE). Extract from CTE (2006)

4.3 Determining BCA Requirements

The BCA includes some tables for each thermal envelope element to provide knowledge about energy efficiency limitation through data obtained from the case.

The thermal envelope is formed by the building fabric and external glazing. By way of example, determining external walls as a part of the building fabric depends only on climate zone; however, floors depend on the construction system used (Fig. 7).

Note that the BCA provides requirements as a minimum R-value (thermal resistance) instead of a maximum U-value (thermal transmittance), like the CTE does. The same can be said for the roof lights or glazing, where a conversion of equaling factors is necessary; e.g. the Solar Heat Gain Coefficient (SHGC) in (1):

$$SHGC = F_{sm} \cdot (1 - FM) \cdot g_{\perp} + FM \cdot 0.04 \cdot U_m \cdot \alpha \cdot 0.87 \quad (1)$$

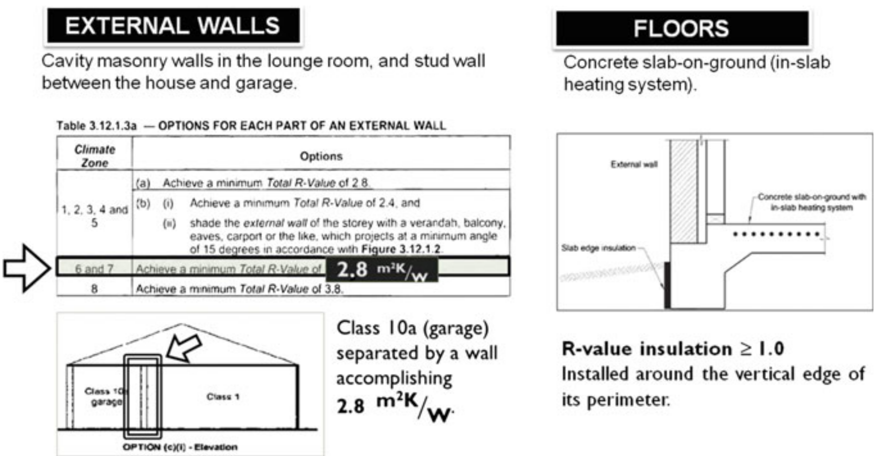


Fig. 7 External walls and floors determining the BCA requirements

Table 4 Determining external glazing BCA requirements. Extract from the BCA (2012)

Floor construction	Air Movement (refer notes)	Constant	Climate zone 1	2	3	4	5	6	7	8
Floor in direct contact with the ground	Standard	C_u	1.650	18.387	14.641	7.929	13.46	6.418	86	3.987
		C_{SHGC}	0.063	0.074	0.062	0.097	0.122	0.153	89	0.234
	High	C_U	1.650	18.387	14.641	7.929	13.464	6.418	5.486	3.987
		C_{SHGC}	0.069	0.081	0.068	0.107	0.134	0.168	0.208	0.257
Suspended floor	Standard	C_U	1.485	16.548	13.177	7.136	12.118	5.776	4.937	3.588
		C_{SHGC}	0.057	0.067	0.056	0.087	0.110	0.138	0.170	0.211
	High	C_U	1.485	16.548	13.177	7.136	12.118	5.776	4.937	3.588
		C_{SHGC}	0.063	0.074	0.062	0.096	0.121	0.152	0.187	0.232

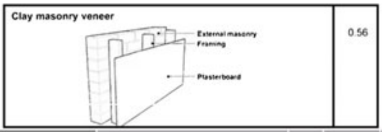
For external glazing, solar radiation has to be considered according to the hemisphere where the city is located; the north facade is the more radiated for the Southern Hemisphere, and the south facade is the more radiated for the Northern Hemisphere (Table 4).

4.4 Insulation Calculations

Construction solutions should be proposed through natural insulation to satisfy not only energy efficiency criteria, but also sustainable criteria.

It is worth noting that insulation prices are considered equal in both countries to conduct this study.

First of all, several natural insulation materials were selected and their thermal characteristics are presented in Fig. 8: dimensions, density, conductivity and price.



BCA Min R-value insulation = 2.8 – 0.56 = **2.24** m^2K/W

CTE Min R-value insulation = 1.16 – 0.56 = **0.63** m^2K/W

INSULATION TYPE	DISTRIBUTION L x W x T (m)	ρ (kg/m³)	λ (W/m°C)	€/m²	MORWELL $e_{min\ ins}$ (m)	MORWELL OBSERVATIONS Need	excess	Sol (€/m²)	PAMPLONA $e_{min\ ins}$ (m)	PAMPLONA OBSERVATIONS Need	excess	Sol (€/m²)
WOOL	PANEL (0.6x1.2x0.05m)	30	0.035	8.5	0.08	2	2cm	17.00	0.02	1	3cm	8.50
	LAYER (0.6x10x0.05-0.1m)		0.043	6.2 – 11.7	0.10	0 – 1	-	11.70	0.03	1 - 0	2cm	6.20
	BULK Filling	12	3.8	3.8 €/kg	0.13	-	-	5.82	0.04	-	-	1.64
	BULK Injected	20	3.8	3.8 €/kg	0.09	-	-	7.15	0.03	-	-	2.01
STANDARD WOOD FIBRE	PANEL (2.5x1.2x 0.08-0.095-0.12m)	350	0.05	2.25 – 2.45 - 2.85	0.11	0 - 0 – 1	1cm	2.85	0.03	1-0-0	5cm	2.25
HEMP	LAYER (0.6x8-10x0.05-0.1m)	30	0.041	6.75-12.9	0.09	1	1cm	12.9	0.03	1-0	2cm	6.75
THERMO WOOD FIBRE	PANEL (1.2x0.6x 0.02-0.08m)	170	0.04	4.95–9.6-18.9-23.2	0.09	1-0-0-1	1cm	23.90	0.03	0-1-0-0	1cm	9.60
CORK	PANEL (0.5x1x0.02-0.1m)	110	0.04	From 6.61 to 27.89	0.09	0-0-1-1-0-0	1cm	25.05	0.03	0 – 1 - 0-0-0	-	8.61
COTTON	PANEL (0.6x1.2x0.05m)	30	0.036	6.8	0.08	2	2cm	13.60	0.02	1	3cm	6.80
	LAYER(0.6x10x0.05-0.1m)	30	0.034	5.8 – 10.4	**0.08**	0 - 1	2cm	**10.40**	**0.02**	1-0	3 cm	**5.80**
	BULK Filling	20	2.2	2.2 €/kg	0.11	-	-	4.93	0.03	-	-	1.39
	BULK Injected	30	2.2	2.2 €/kg	0.09	-	-	6.21	0.03	-	-	1.75

Fig. 8 Example of insulation calculation for external walls

Depending on the city (Morwell or Pamplona), Fig. 8 shows the required insulation thickness, the number of panels needed and/or excess thickness, as well as the final economic cost. According to this criterion, cotton-made insulation panels were selected, as highlighted in Fig. 8.

5 Results

The CTE requirements were taken from the CTE-DB HE document and were converted into the units used by the BCA to compare them, as follows in expressions (2–6):

BCA:

$$C_u = \frac{\sum_{i=0}^{i=n} (A_i \cdot U_i)}{\sum_{i=0}^{i=n} (A_i \cdot SHGC_i \cdot E_w)} \tag{2}$$

$$\sum_{i=0}^{i=n} (A_i \cdot SHGC_i \cdot E_w) = 12.44 \tag{3}$$

$$U_H = 0.503 \cdot C_u \tag{4}$$

CTE:

$$U_H = \frac{\sum_{i=0}^{i=n} (A_i \cdot U_i)}{\sum_{i=0}^{i=n} A_i} \tag{5}$$

$$\sum_{i=0}^{i=n} A_i = 24.75 \tag{6}$$

Table 5 presents the strictest values in italics.

Table 5 Comparison of thermal limitations

	BCA—part 3.12	CTE DB-HE1	
		Original units	Unit conversion
Roofs	*Total R-value ≥5.1 m^2K/W*	U-value ≤0.49 W/m^2K	R-value ≥2.04 m^2K/W
Roof lights	SHGC ≤ 0.72	$F_{L\ luc}$ = 0.36	*SHGC ≤ 0.568*
	Total U-value ≤ 5.7 W/m^2K	*$U_{rl\ max}$ = 3.5 W/m^2K*	$U_{rl\ max}$ = 3.5 W/m^2K
External walls	*R-value ≥2.8 m^2K/W*	U-value ≤0.86 W/m^2K	R-value ≥1.16 m^2K/W
Floors	*Total R-value ≥2.176 m^2K/W*	U-value ≤0.64 W/m^2K	R-value ≥ 1.56 m^2K/W

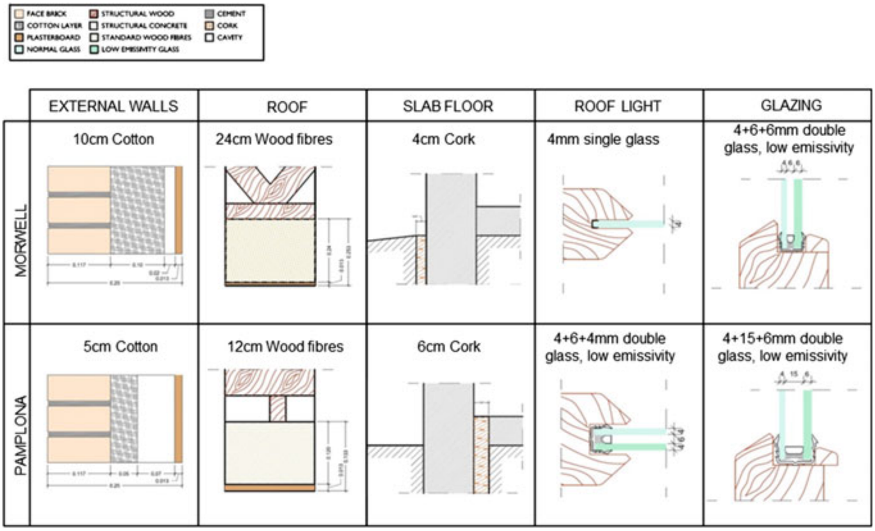


Fig. 9 The construction solutions selected for the building thermal envelope

The construction solutions selected as the study results, using natural insulation, are summarized graphically in Fig. 9.

After analyzing the case study results, it was found that the requirements for opaque thermal envelope elements are more restrictive in the BCA, while the CTE is more restrictive for the glazing and transparent parts of the thermal envelope. The CTE limits conditions more because it takes the solar orientation of facades into account, whereas the BCA limitations are based only on climate zone, air movement type and floor typology.

However, CTE in Spain also introduces the U_{lim} concept for each thermal envelope element to be accomplished, which is always more restrictive than U_{max} values, and refers to each independent thermal envelope element. Then for specific cases, CTE can be more restrictive.

It also worth noting that in most of cases, the BCA considers more factors to determine the minimum R-values, while the CTE contemplates only the relative climate zone. Some of the reasons to explain the stronger BCA restrictions include a more extreme climate (natural disasters, extreme weather, etc.), typical dwelling typologies, specific legislation per building type, etc.

6 Software Development

All the methodology presented to make this comparison between the BCA and the CTE was automated by creating a software based on the Visual Basic programming language. This tool allows users to check requirements for any city. Figure 10 shows the software interface.

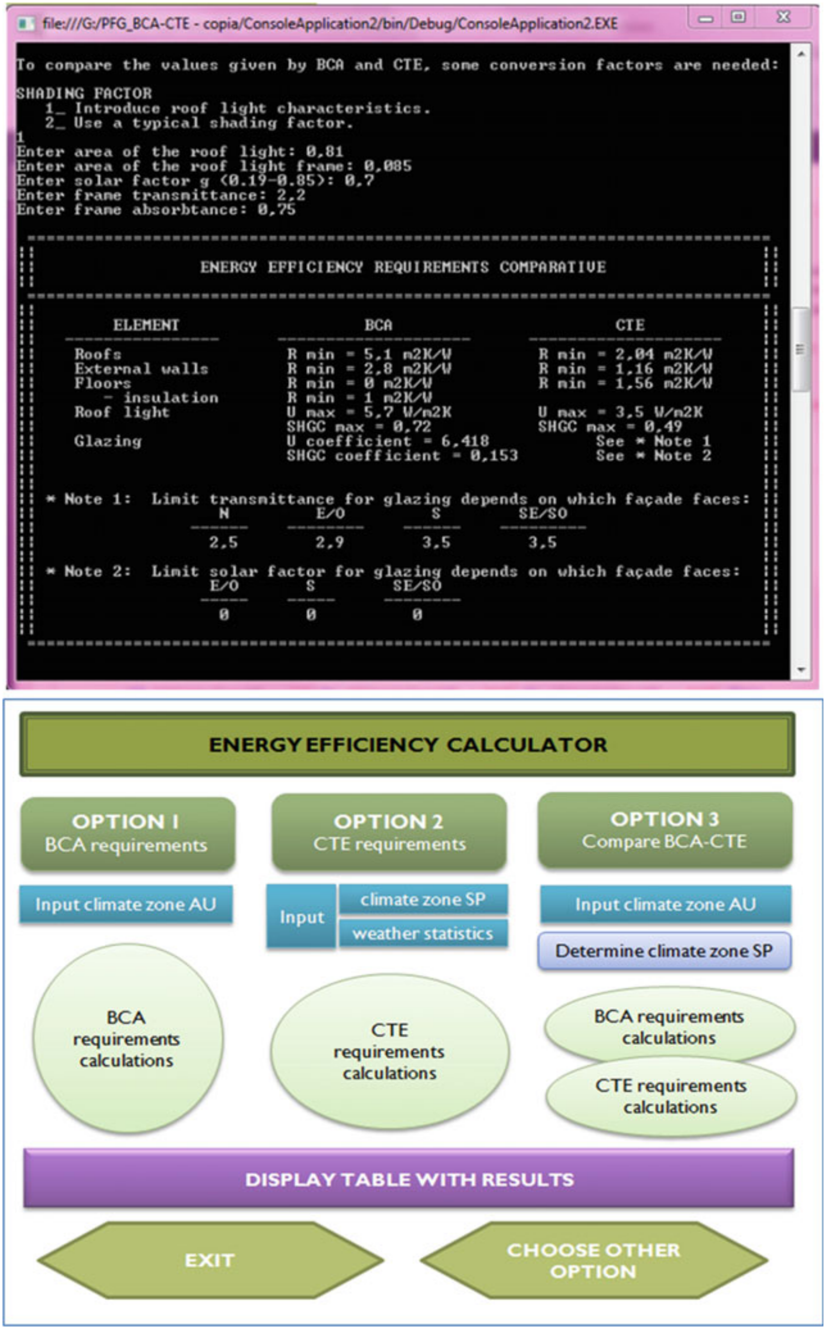


Fig. 10 Visual Basic program scheme functionality and appearance

7 Conclusions

The study presented herein allowed to compare the requirements on energy efficiency of Spanish and Australian regulations, CTE and BCA, respectively. The BCA was analyzed in detail by studying the structure and finding the correlation of sections with the CTE. In some cases, certain aspects included in the BCA were not found directly in the CTE. Therefore, it was necessary to resort to other regulations, such as the RITE. The building classification according to usages and climate zones were also compared for both countries. Usages of Australian buildings were more divided as more building types are found there.

To illustrate the comparison made, a detached house was analyzed by implementing the energy requirements for both building codes to provide construction solutions through natural insulation. The results obtained of this comparison were highly interesting, showing that while, which show that while the BCA is more restrictive for opaque thermal elements than the CTE, the CTE is more restrictive for the glazing and transparent parts of the envelope.

Nevertheless, the CTE not only works with a maximum U-value/R-value for each independent element of thermal envelope typology, like the BCA does, but also requires the accomplishment of Ulim for the groups of elements that take part in the same construction envelope element, This implies introducing more restrictive values into some elements than the BCA.

In conclusion, this case study identified the main points that presented the most important differences between both regulations, highlighting which one is more restrictive depending on the aspect analyzed.

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Energy Efficiency as a Strategic Planning Tool in a House Type Project

J.A. Castelán Peña, C. Aparicio-Fernández and J.L. Vivancos

Abstract Energy efficiency in a project to build house types is an essential tool in strategic planning as it provides the opportunity to reduce energy consumption, to design houses with low energy demands and to promote more sustainable constructions. This paper analysed a house type project in Mexico by considering different climate zones to explore and study the thermal behaviour of houses under different operating conditions. The analysis was performed with the TRNSYS software, transient simulation software used for designing and optimising energy systems and the thermal simulation of buildings. The results of the housing type project's performance in different structural designs for distinct climate zones are presented, and its utility for implementing strategic planning to design, construct, use and maintain energy-efficient homes was explored in hygrothermal comfort terms.

Keywords House type · Energy demand · Climate zone · Energy consumption · Hygrothermal comfort

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1 Introduction

In recent years, Mexico has developed strategies that have been used to reduce not only the impact of buildings on climate, but also their energy consumption. Technological and social innovations play a key role in making buildings sustainable habitats (Acosta and Cilento Sarli 2005). One of the strategies most widely studied nationally and internationally is the orientation of houses. Researchers like Solís (2008), Krishan (1996), the Mexican Commission to Promote Housing (CONAFOVI) (2006) and Morillón (2011) in Mexico have agreed on the importance of proper building orientation.

As technology advances, new tools and materials have appeared for designing and building optimized houses with low energy demands. Insulation concepts, such as a northern orientation, shading, high-tech glass (Giménez Molina and Lauret Aguirregabiria 2008), are no longer sufficient for efficient housing. When used properly in the strategic planning of projects to build housing types, transient simulation tools provide the results to help optimise resources.

1.1 Objectives

The aim of this paper is to determine the energy performance of each housing type proposed in different climate zones of Mexico. The specific objectives are to:

- Identify orientation with lower energy demand for each housing type in different climate zones
- Analyse the effect of geometry on a standard house in different climate zones
- Analyse the effect of glazing on a standard house in each climate zone
- Analyse the effect of the proposed optimal envelope with lower energy demand for each housing type in different climate zones
- Identify potential cost savings per analysed case

In this work, two house types were analysed in four different climate zones in Mexico; Chihuahua, Midwest: Mexico City in the north; San Cristóbal and Tapachula in Chiapas in the south. The last two cities belong to the same state, but have a different climate, hence the interest in analysing them. TRNSYS 17 was used as the simulation software, which is normally used to simulate the thermal behaviour of transient systems (TRNSYS 2014). This software enabled to calculate the energy demand of housing types during a given period of time under different conditions.

2 Methodology

2.1 Building Type

The analysis was performed in two detached houses (two compact houses with a floor area covering 36 m^2) in order to understand their thermal behaviour in an extreme scenario (Infonavit 2009). The analysis was done after performing the following steps:

- A 3D geometry of the house was introduced with "Type building project multizone" of the TRNSYS software,
- All the calculation parameters considered in the study (geometry, orientation, thermal envelope, glass area and expected HVAC systems) were established
- The meteorological data of the studied climates were defined
- Simulations were done using several constructive proposals that employ different materials

2.2 Geometry

Two geometries with an equal constructed area were analysed to see the impact of shape and compactness on the results. Table 1 shows the dimensions of the houses considered. The volume of air varied slightly for each house as the thickness of the facade was not counted. The facade envelope varied and affected the useful house area; that is, the compactness of the house differed according to its shape because the surface exposed to outside walls varied (compactness (m) = volume/envelope surface) (Fig. 1).

2.3 Orientations

The following orientations were considered for House A and House B (Fig. 2):

- North facade. Main access to housing
- South facade. Exit to multipurpose garden or patio in the backyard
- East Facade
- West facade

Table 1 House types considered

Type	Dimensions (m)	Built area (m^2)	Useful area (m^2)	Height (m)	Volume of air (m^3)
House A	4 × 9	36	32.16	2.3	74.04
House B	6 × 6	36	32.49	2.3	74.73

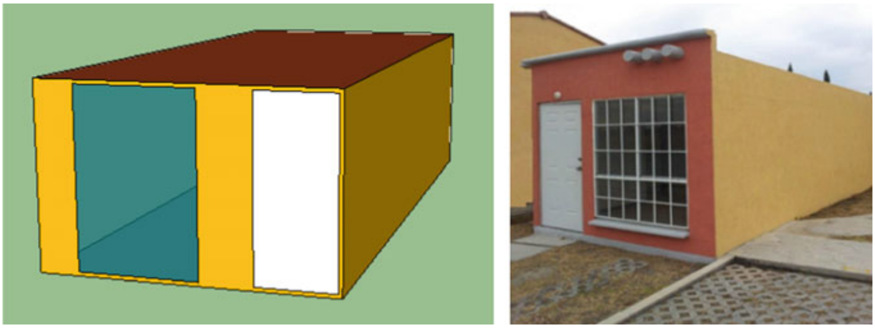

Fig. 1 House type analysed

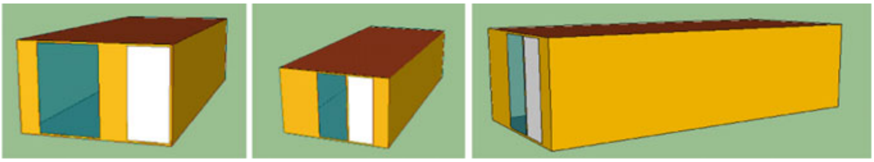

Fig. 2 House type analysed. Housing access (Windows 37.5 %); backyard (Translucent 25 %); walls

Houses were rotated clockwise in 45° intervals in relation to the orientations considered in the simulation.

2.4 *Climate Zones*

Analysing different climate zones in Mexico was interesting since this large country includes several climates that affect comfort inside homes. Therefore for this study, four climate zones located in three different states were considered. Table 2 shows these locations, and the average temperature and relative humidity data. The database used was Meteonorm (weather data) which included outdoor temperature, relative humidity, solar radiation and wind, taken every 10 min over an annual period. The software used these data to calculate the thermal behaviour of the houses in a transient regime.

2.4.1 Weather Data

When a new project is created with the TRNSYS software, the model's "weather data" (Type109 which reads tm2 files) are configured. Type109 allows the data of different climate zones to be inputted. This allowed the analysis of the thermal

Table 2 Summary of the meteorological data per climate zone

State	City	Climate	Average annual temp °C	Max temp °C	Min temp °C	% Relative humidity
Chihuahua	Chihuahua	Dry and semi-warm	18.2	38	−7	45
Federal District	Federal District	Mild and rainy	16.6	28	−1	62
Chiapas	San Cristobal	Mild and humid	15.1	22	8	74
Chiapas	Tapachula	Warm and humid	25.4	40	8	40

behaviour of a building model in different climate zones. As previously indicated, the software in the transient regime offers more realistic results since the thermal behaviour of houses varies constantly according to external environmental conditions.

2.5 Parameters

The parameters considered in the house proposals were:

- Air leakage, which occurs through the building envelope. The infiltration value was difficult to determine without performing an in situ test, but a value of 0.2 h^{-1} was set. This value was taken as the standard in houses with low energy demand. Although the infiltration value was low, it was considered as no data was available
- The indoor comfort temperature ranged between 19 and 26 °C
- The indoor relative humidity was 55 %
- The thermal envelope:
  - Windows; when the baseline was contemplated, windows with single clear 6-mm glass and an aluminium frame with no thermal break were considered. This was the constructive solution that we found on a regular basis. Hence improved double glazing (clear, 6-8-6 mm) was proposed. In both house types, the same percentage of windows were considered; 37.5 % on the facade with the main entrance; 25 % on the side facing the backyard.
  - Facades; considered the vertical enclosure that came into contact with the outside. In the baseline, a conventional construction solution in Mexico was considered. From this type, other typologies were contemplated to improve insulation by diminishing the thermal transmittance of the envelope and analysing its influence. Table 4 shows the ordered layers from the inside to the outside.

- Floor; the lower enclosure was considered a concrete slab that came into contact with the ground. The input data used in this enclosure are presented in Table 5.
- Flat roof; an upper horizontal boundary that came into contact with the external environment. Table 6 presents the data of the materials used for the most common configuration used in Mexico. Layers were arranged from the outside to the inside.

To calculate energy costs, the Mexican residential tariff system, in Mexican Pesos (MXN), was taken into account (Comisión Federal de electricidad 2014), which was based on a set of three consumption scales: first for monthly consumption below 75 kWh ($0.807/kWh); other costs for the following 65 kWh ($0.978/kWh); and those above 140 kWh ($2.862/kWh).

2.6 Simulation Process

After inputting all the data, strategies were varied to ensure that the proposals reduced the energy demand more effectively. With the simulation software, the energy demand required in each house to ensure the previously established comfort parameters was obtained. Energy demand was estimated as kWh/m^2 year.

The initial case study began with the two proposals for a traditional house type which main entrance had a northerly orientation. Of all the proposals, the results of the four different climate zones in Mexico were obtained. Then the house was rotated 45° to change and optimise its orientation. By considering the values of Sect. 2.5, the thermal envelope of the building was also modified. This determines the best building solution for different climate zones. Subsequently all the results obtained were analysed and compared in order to decide which strategy was the best depending on the climate zone and house model at hand for construction were compared depending on the climate zone and house model being analysed. This made architectural development projects.

3 Cases Studied

This work combined all the previously discussed proposals for climate zone, building shape and thermal envelope. To analyse the results of each proposal separately, different strategies were adopted to progressively start from the initial case, called Case 0. Then the cases proposed for the analysis were placed in order:

Case 0: House A and House B. The initial proposed case study. Conventional construction solution (Facade. Strategy 01).

Case 1: Influence of shape on the house type (House A and House B). Case 0 was considered.

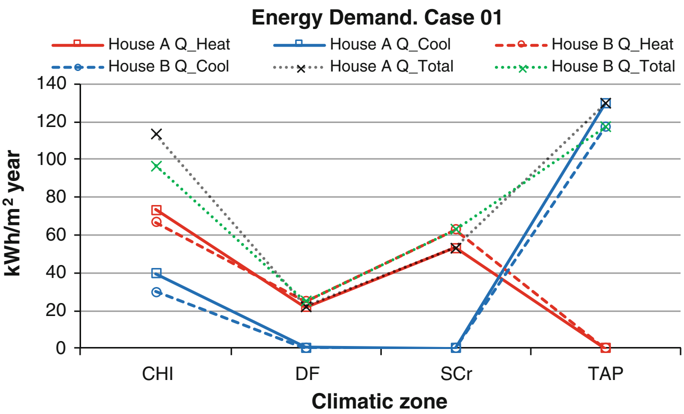

Fig. 3 Comparison for Case 1. Energy demand for heating and cooling the house, and total annual demand for different climate zones in Mexico (kWh/m^2 year)

Case 2: Influence of orientation for each house type (House A and House B). Case 0 was considered.
Case 3: Influence of type of glazing. Single and double glazing.
Case 4: Influence of adding thermal insulation on the outside of the envelope, and considering windows with double glazing (Facade. Strategy 02). It was analysed based on Case 3.
Case 5: Influence of thermal insulation of the facade on the exterior and inside the wall (Facade. Strategy 03).

The results of the two house types (House A and House B) considered for an annual period are plotted in Fig. 3. These are the reference data and correspond to Case 1, which was house type. These initial data were used to analyse the energy demand results. Then the energy demand results for heating and cooling the house, plus the total annual demand for the different climate zones in Mexico, were summarised.

3.1 Case 1. Influence of Shape

To understand the thermal behaviour of these houses, the cooling and heating energy demands in each climate zone were analysed to establish a baseline that considers the data from an original project, which is currently being built in Mexico. The parameters used to calculate the thermal envelope were:

- Single glazing. Strategy 1 in Table 3
- Envelope, data provided in Table 4. Strategy 1 was firstly analysed
- Floor. The data proposed in Table 5 were used

Table 3 Windows. The facade strategies used in the simulation

	Glazing types	Thickness (mm)	g	U (W/m^2K)	ε
Strategy 1	Single (clear)	6	0.83	5.7	0.89
Strategy 2	Double (clear)	6-8-6	0.76	3	0.89

Table 4 Facade. The facade strategies used in the simulation

	Material	Thickness (m)	ρ (kg/m^3)	λ (W/mK)	R (m^2K/W)	Rt	U (W/m^2K)	Cp (J/KgK)
Strategy 1	Plaster	0.015	1200	0.57	0.03			1000
	Brick	0.14	1020	0.67	0.21			1000
	Cement	0.015	1350	0.7	0.02	0.26	3.90	1000
Strategy 2	Plaster	0.015	1200	0.57	0.03			1000
	Brick	0.14	1020	0.67	0.21			1000
	Insulation	0.015	100	0.07	0.21	0.45	2.22	1000
Strategy 3	Insulation	0.015	100	0.07	0.21			1000
	Brick	0.14	1020	0.67	0.21			1000
	Insulation	0.015	100	0.07	0.21	0.60	1.57	1000

Table 5 Ground floor. Reinforced concrete slab

	Material	Thickness (m)	ρ (kg/m^3)	λ (W/mK)	R (m^2K/W)	Rt	U (W/m^2K)	Cp (J/KgK)
Strategy 1	Reinforced concrete	0.1	2500	2.5	0.04	0.04	25.00	1000

- Flat roof. The data proposed in Table 6 were used.
- The values of the thickness, composition of walls, total thermal resistance (Rt) and overall thermal transmittance (U) of envelopes were considered, and were set according to the original project data in Table 4. This project was taken as a reference results could be compared from.

Figure 3 illustrates how energy demand varies per house type. In Chihuahua (CHI), House B was 14.67 % more efficient than House A. In the Federal District

Table 6 Flat roof

	Material	Thickness (m)	ρ (kg/m^3)	λ (W/mK)	R (m^2K/W)	Rt	U (W/m^2K)	Cp (J/KgK)
Strategy 1	Waterproof membrane systems	0.015	1100	0.23	0.07			1000
	Reinforced concrete, insulated	0.25	710	0.17	1.47			1000
	Gypsum	0.015	1200	0.57	0.03	1.56	0.64	1000

(FD), House A was 10.02 % more efficient compared to House B. House A also displayed better performance in San Cristobal (SCr) with efficiency at 15.59 % compared to House B. However in Tapachula (TAP), in a city of the same state (Chiapas) as San Cristobal (SCr), but with a different climate, House B was more efficient by 9.61 %.

We can see in Fig. 3 how climate zone influences energy demand. The first result for cooling and heating demands throughout the year in CHI showed that heating demand was higher than cooling demand. In climate zones FD and SCr, the cooling demand was considered zero or near zero. So the proposed strategies would always be influenced by heating demand during cold periods. Lastly in TAP, only cooling demand existed throughout the year, and given this influence, the strategies were analysed only for cooling. These climate zones cover the most varied climates of Mexico.

In Fig. 3, the compactness of the house was analysed with Case 0, the construction type most commonly used in Mexico. Even though the differences were not marked, the total demands in CHI and TAP were lower for House B, and they were lower for House A in FD and SCr. The same orientation was still seen as the geometry of houses is crucial to reduce energy demands. Therefore, if this tool was used when designing a home, optimised house energy performance would be achieved. A single house model for all states should not be considered, not even in the same state if the climates differ.

From an economic point of view, it was estimated that climate zones CHI and TAP can obtain monthly energy savings in bills of about $100, plus the advantage that this approach would not imply significant investments.

3.2 Case 2. Thermal Behaviour of Different Orientations

In order to know the best orientation for each house type tested, some simulations were done by changing orientation: eight different orientations with variations in orientation by rotating the house in intervals of 45°.

For this analysis, House A, House B and Case 0 (single glass; facade strategy 1) were also considered. Figure 4 shows the results of House A and House B in different climate zones. Then the annual energy demands obtained for the analysed different climate zones were summarised after considering the initial house type case as being unmodified. Let's remember that orientation 0 meant that the main entrance with 37.5 % of glazing was oriented northward with access to the garden, and with 25 % glazing oriented southward.

The obtained data showed that minimum global energy demand coincided with the baseline orientation only in one climate zone, so orientation in most areas improved. The climate zone with the most improved orientation was house B in CHI, where both cooling and heating demands decreased with a 180º rotation because it is the climate zone with lower heating and cooling demands. House A

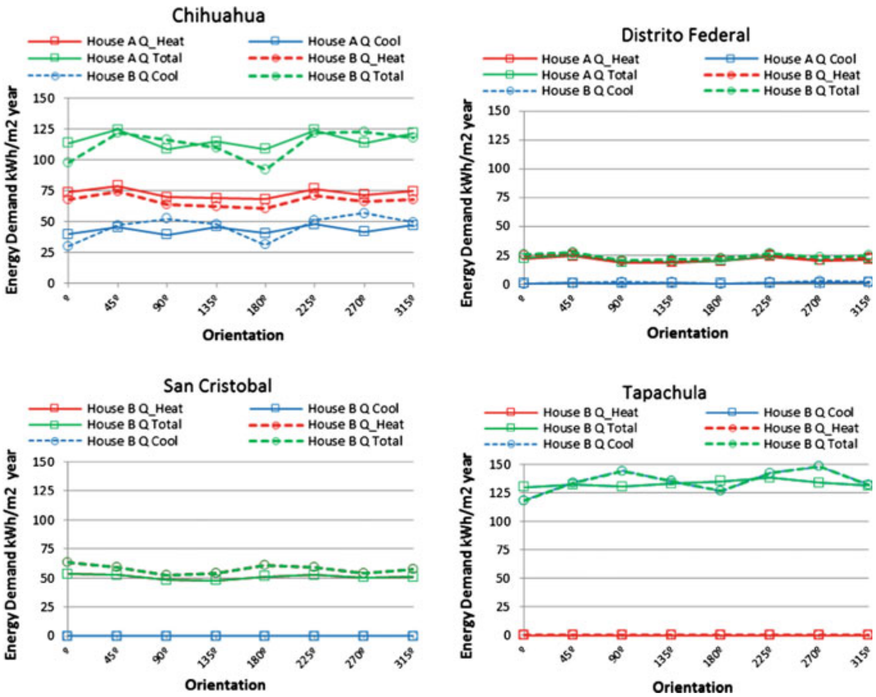

Fig. 4 Comparison for Case 2. Energy demand for heating and cooling the house, and total annual demand (kWh/m^2 year)

was also located in this climate zone, where the orientation effect changed the most. A reduction of 4.09 % was obtained for House A and one of 5.81 % for House B.

In the FD, the cooling demand was negligible throughout the year, where the overall heating demand value changed the most. In this climate zone, the greatest reduction was obtained when turning the house 90° in both house proposals. When analysing the percentage of global reduction, reductions of 15.66 % for House A and of 17.69 % for House B were obtained.

For SCr, similar results were obtained because there was no cooling demand, so the improvement proposals would be the same. The most marked reductions were obtained when turning the house 135° and 90° for House A and B, respectively. The overall drop in percentage was 9.8 % for House A and 18.1 % for House B. From an economic point of view, it was estimated that a monthly saving of about $90 (MXN) in energy bills could be achieved for this climate zone, plus the advantage that this approach would not imply significant investments.

The last climate zone analysed was TAP, which presented no cooling demand. Here the lower demand was obtained with the initial value (0°). This orientation was considered optimal. The orientation should be optimised according to climate zone. The guidelines for all climate zones should be rectified, except for TAP. In the other cases analysed from the most favourable cases, the following were examined:

- Chihuahua: House A: 180°; House B: 90°
- Federal District: House A: 90°; House B: 90°
- San Cristobal: House A: 135°; House B: 90°
- Tapachula: House A: 0°; House B: 0°

3.3 Case 3. Thermal Behaviour of Glazing

The influence of the glass used was analysed to discover its real impact on the original project. In this case the original single 6-mm glass was changed to a double glazing type. The obtained energy demand was compared with the reference and the thermal behaviour of the windows was determined.

The following characteristics were considered:

- Case 1
- Case 3. Double Glazing (clear, 6-8-6 mm).

The envelope values are as described in Sect. 2.5. The cost of replacing glass was estimated at $892.71 (MXN), which allowed a payback time to be considered.

It was possible to test the thermal behaviour of glazing for House A and House B in CHI, and savings of 13.39 and 20.50 % were respectively obtained with the proposed double glazing design. In the FD, the improvements achieved were 21.54 % for House A and 37.81 % for House B. In SCr, the saving with double glazing was 17.94 and 28.60 % for House A and House B, respectively. The double glazing in TAP gave a profit of 10.03 % for House A and one of 16.19 % for House B. The improvement accomplished from changing glass affected affected all houses in all the climate zones, regardless of the initial case. Reducing heat and cold loss through glass is always beneficial for houses; in most cases, the payback time was less than 1 year, except for the FD, which was between 3 and 4 years depending on house type.

3.4 Case 4. Thermal Behaviour of Exterior Insulation

Case 4 was analysed from case 3, but by changing the outer envelope (Strategy 2). The energy demand results allowed to make a comparison with previous cases. Double glazing with thermal insulation on the outside was considered (Strategy 2), with a floor and flat roof as described in Tables 3 and 4, respectively. The cost of insulation on the facade was estimated at $/m^2 105.60 (MXN), which would mean an investment of $5822.97 and $5337.23 (MXN) for House A and House B, respectively.

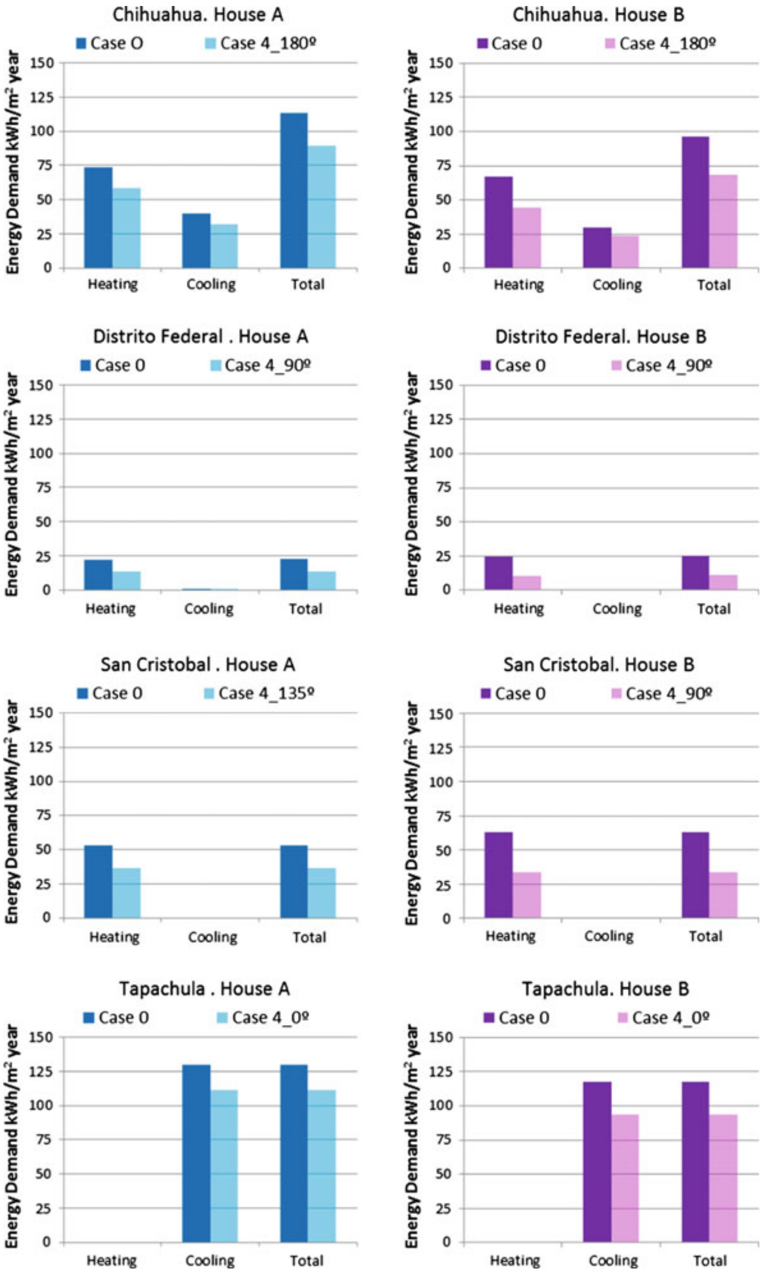

Fig. 5 Comparison for Case 4. Energy demand for heating and cooling the house, and total annual demand (kWh/m^2 year)

The results presented in Fig. 5 show the thermal behaviour of House A and B with insulation placed on the facade. In CHI, improvements of 59.64 and 64.84 % were respectively obtained for houses A and B, which led to a significant reduction in the energy demand compared to the reference.

For the FD, the results showed a reduction of 85.81 and 87.76 % for House A and B, respectively. In this case, House A in SCr displayed a thermal behaviour that was 73.96 % lower than the reference, and House B exhibited an improvement of 78.10 % compared to the original. In TAP, the energy demands were lower: 56.48 and 55.05 % for type A and B, respectively.

Exterior thermal insulation was considered to protect the facade from daily temperature variations. This exterior insulation reduced the thermal transmittance value of the envelope by nearly half the initial value. This gave good results in all cities and for all climates, although greater reductions were obtained in the FD and SCr than in CHI and TAP, which had more extreme weather and a lower demand reduction. However in all cases, a reduction of over 50 % was achieved compared to the reference. In most cases, the payback time was 1 year, except in the FD, which was between 10 and 11 years depending on house type.

3.5 Case 5. Thermal Behaviour of the Interior and Exterior Insulation Envelope

In this case the facade envelope was insulated on both sides, that is, inside and outside, with insulating material. The cost of insulation on the facade was estimated as $\$/m^2$ 211.19 (MXN), which implies an investment of \$10,753.24 and \$9781.76 (MXN) for House A and House B, respectively.

In case 5, double glazing and plaster facade insulation were considered (Strategy 3), as were the floor and flat roof described in Sect. 2.5.

House A and B in CHI were 77.46 and 80.06 % more efficient, respectively, than for House A taken as a reference. For the FD, the result was 96.90 % for House A. In SCr, the reductions were 88.74 and 89.90 % for types A and B, respectively, compared to the reference. In TAP, they were 77.13 and 71.97 % for House A and B, respectively. Insulation placed on the exterior and interior considerably reduced the energy demand of these houses for both heating and cooling demands. In all cases, this measure proved successful to reduce the energy demand by more than 70 % compared to the reference.

From an economic point of view, it should be noted that the payback time was 2 years in most cases, which indicates the economic viability of the proposed strategies. This time could be 7 for SCr and 18 years for FD for House A.

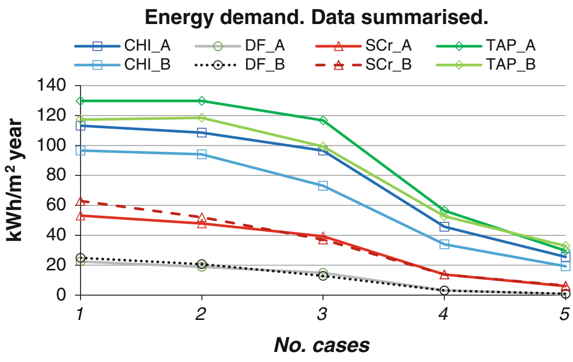

Fig. 6 Summary of the results. Total energy demand (heating and cooling; kWh/m^2 year)

3.6 Summary

Since there are many results, Fig. 6 summarises all the cases and shows the improvements achieved. The reduced global energy demand in each climate zone is highlighted for all the proposed strategies. The most significant reduction in energy demand was obtained by insulating the facade on the outside. We can also observe how energy demand was reduced when compared to the reference.

4 Conclusions

This paper indicates the advantages of using a software in the transient regime to facilitate changing climate zones consideration (Aparicio-Fernandez et al. 2013). This allowed to develop different strategies and to optimise the construction solution according to climate zone.

The analysis of the geometry and compactness of the building were objectives of the study. The obtained results demonstrate that geometry influenced energy demand in the all climate zones, and that both house type proposals have different energy different demands depending on the climate zone they are located in.

Glass was one of the studied strategies, where a reduction in demand of up to 38 % was shown for the Federal District. Despite this result being combined with compactness and geometry, reducing heat and cold loss through glass is a strategy that should be considered when designing houses.

The strategies discussed to further reduce energy demand included insulating walls, which gave reductions of up to 97 % in combination with the other proposed strategies. Thus a change in the envelope can be considered a key strategy in designing and constructing buildings as it limits the use of active conditioning system spaces (Morrissey and Horne 2011).

Even after showing that envelope shape and glazing are important for the development of a constructive strategy, they were also recommended as they allowed improvements up to 18 % depending on climate zone. It was emphasized that in San Cristobal and Tapachula, both of which are found in the Chiapas State, weather was crucial to establish the orientation of houses.

These results showed that for San Cristobal and the Federal District, it was easy to obtain houses with energy demands lower than 15 kWh/m^2 year, which is the Passivhaus standard (Rodríguez-Soria et al. 2014).

Countries' economic development takes into account certain economic aspects. The potential savings made from adopting the different strategies demonstrated herein were estimated. The overall strategies can be paid back in a short time; indeed for Tapachula and Chihuahua, the payback time can be under 2 years. In the Federal District, the payback times can take longer, but are shorter than the houses' lifetime.

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Predictive Probabilistic Functions for Energy Prices as an Input in Monte Carlo Simulations

Adrien J.P. Grid, Andrés Ortuño, M. Socorro García-Cascales and Juan Miguel Sánchez-Lozano

Abstract The continuous increase in energy costs and the volatility of energy prices are enforcing the implementation of energy efficiency measures (EEM) in companies. The choice of EEM in most cases is based on Pay-Back (PB) criteria, and in several cases on NPV and IRR criteria. In all these cases, it is necessary to estimate the price of energy in the following years so as to be able to study the profitability of the proposed EEM. Energy prices: electricity, biomass, petroleum, natural gas… change greatly throughout the period of a project, and their values are not easy to predict. If probabilistic functions are used to define the evolution of energy prices, in the period of the project, the economic parameters (PB, IRR, NPV) could also be obtained as probabilistic functions, by applying Monte Carlo Simulation Methods. This paper shows how to obtain the probabilistic functions that best describe the variation of energy prices in the period of a project, and how to apply the Monte Carlo Simulation Method to obtain a better approach to predicting future energy prices.

Keywords Risk management · Energy services · Monte carlo · Energy management · Project management

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1 Introduction

Continually spiralling energy costs and the volatility of energy prices are enforcing the implementation of Energy Efficiency Measures (EEM) in companies. Selecting the EEM to implement is mainly based on Pay Back (PB) criteria, and in several cases on Net Present Value (NPV) and Internal Rate of Return (IRR) criteria, (Baca Urbina 2001), (Sapag-Chain and Sapag-Chain 2000).

These parameters, PB, NPV and IRR, are usually given as a number, calculated based on their formulas, where the different values to input in the variables included in the formulas are not easily predicted or estimated. For instance, variables such as the operating hours of an installation; or the efficiency or performance of equipment; or the price of the different fuels in the life of the project, all of these must be specified in values and estimated through the life of the project, in order to be able to calculate the PB, NPV and IRR parameters.

During this calculation process assumptions are made regarding a lot of estimates of these variables, without considering the uncertainty or risk associated to that estimation. The possible variability of the assumed values is not taken into account, and therefore nor is the risk associated to each estimated value.

During the decision process in complex projects and especially in those with a high economic impact in the business, it is necessary to use more advanced tools and methodologies which are able to take into consideration the risk associated to the estimation of the behavior of the variables that affect the profitability of the project. With this approach, a better decision can be taken, considering not only static values but also the uncertainty associated to those values, the probability of deviation from the predictions, and its impact on the results of the project. Showing PB, NPV and IRR in the form of probabilistic functions helps decision makers to select between the different options in the project, since it allows them to study the results of the project also in the form of probabilistic functions.

One of the most influential variables needed when selecting among EEMs is the variation of the energy prices (fuel and electricity), or current prices and future prices of energy sources. For instance, if the decision maker has to decide between installing thermal—electric gas cogeneration equipment or a biomass boiler, a critical variable to consider is the price of biomass and natural gas today and in the future. Therefore, it is necessary to estimate the price of fuels in forthcoming years to study the profitability of each EEM proposed.

Energy prices: electricity, biomass, petroleum, natural gas… change greatly during the lifetime of a project, and their values are not easy to predict. If probabilistic functions are used to define the evolution of energy prices throughout the duration of the project, the economic parameters (PB, IRR, NPV) could also be obtained as probabilistic functions, by applying Monte Carlo Simulation Methods.

The following sections summarize how to obtain the probabilistic functions that best describe the variation of energy prices in the lifetime of a project, and how to apply a Monte Carlo Simulation Method to obtain a better approach to future energy prices. Therefore, the following sections:

- Briefly explain the principle of a Monte Carlo Simulation Method.
- Show how to apply probabilistic functions that suit the development of the different fuel prices, preserving the risk or uncertainty.
- Show how to add these functions in a Monte Carlo Simulation to predict the fuel prices, controlling their uncertainty.

Subsequently, future studies will use this data to achieve these final objectives:

- To employ these prospected fuel prices to calculate the EEM results.
- To calculate financial parameters such as NPV, PB and IRR based on these prices, and therefore to transfer the uncertainty to these parameters.
- To study the effect of the uncertainty in the decision making process from these financial parameters.

2 Monte Carlo Simulation Method

Simulation can be defined as the process of designing a model from the real system and apply it to real experiences over it, in order to understand the behavior of the system or to evaluate several strategies for the operation of the system (Shannon and Bernal 1988). That is to say, unlike traditional mathematical models that are made from real systems that are solved in an analytical way to obtain their results or outputs from different inputs, simulation models are put into operation and are not solved (Ramos 2010).

To make the correct decision it is necessary to understand how the system will respond to a particular action. This can be done by experimenting directly through the real system, but economic, safety and other factors generally make it unfeasible to proceed in that way, besides being at times clearly impossible. In order to overcome these issues, the real system is replaced by another system which most of the time is a simplified variation of it. This latter system is the model to use to run the needed experiences without the issues commented. The process of running experiences in a model is called simulation (Tarifa 2001).

Shapiro (2001) states that simulation is the most common method for making models that could include random behaviors of a great number and variability of components, in such a way that the dynamic behavior of the system can be evaluated over time.

Concerning this paper, Monte Carlo simulations are used herein; they use random variables and are useful in the decision making process of EEM selection and managing the uncertainty.

Simulation offers the decision maker several possible results or outputs, as well as the probability of them happening. It shows the extreme possibilities (the result of deciding on the most risky alternative), and the most conservative possibility, as well as all the possible consequences of intermediate decisions.

3 Methodology and/or Case Study

3.1 Energy Price Data Collection

In the current study, historic data of energy prices has been needed for different fuels' prices, as well as for the price of electricity. This data is crucial to identify the trends of the prices and their uncertainty. Energy prices at industrial level are more variable than domestic prices. The prices can vary monthly or even during the month. In order to obtain historic data where changes in the trends can be detected, it is necessary to have as much data as possible.

Data of energy and fuel prices is available from numerous sources such as: (Platts 2013), (Europe's Energy Portal [EEP] 2013), (International Energy Agency [IEA] 2013), (Asociación española de Operadores de productos PETROLÍFEROS 2013 [CORES] 2013)…. Certain prices, such as those of natural gas and electricity, are also listed in the (Oficina Estadística de las Comunidades Europeas 2013) and include reliable and ample data. Other fuels such as biomass have little information regarding their prices, mainly because their market presence is relatively recent.

It is also necessary ensure that the data collected is a mean of comes from surveys in the selected country. In order to adjust as far as possible to the reality of the prices in a particular place, a correct approach can be to contact local suppliers of fuel and electricity to check their prices and compare it with the data obtained from other sources. An adjusting coefficient can be applied to better fit the prices in a particular zone compared to global prices. That coefficient is the relation between the present price sourced through a local supplier and the present price included in the historic global data source. It is an effective simplification that assumes that the relation or difference between local price and global price remains constant over time.

Prices need to be expressed in the same currency and related to the same energy unit. In this particular case study, €/kWh has been used.

Once the historic data has been obtained, it must be statistically analyzed. Different types of regressions are used to try to fit the scatter diagram to a curve of an analytic expression. This expression would be the model proposed to follow the prices of fuel and electricity. This model can be surveyed through time without losing credibility. It cannot be assumed that with historic data from the 1980s a good survey of present and future prices can be made, but it is acceptable that with historical data from recent years there would not be a change of trend over the next five or six years.

These surveyed models are the simplest models known to estimate future fuel prices. However, they fail to include data regarding the assumed uncertainty or, from the point of view of risk management, they do not provide any data or measure of the risk assumed using those models.

It is therefore necessary to measure the dispersion of real data versus the model used, and to assume that this dispersion continues in the surveyed side of the model. It should be noted that to calculate the standard deviation of that data is not an acceptable solution, since the standard deviation measures the deviation of that data from their mean, and in this case study that is not the dispersion sought, but rather the dispersion of the data with regard to the model. Therefore the deviation would be calculated with:

$$\sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{(n-1)}} \quad (1)$$

where:

- x_i is the real price for year i.
- y_i is the surveyed price for year i.
- n is the quantity of historic data.
- σ is the deviation of the model with regard to real data.

The difference between the standard deviation and the deviation calculated in Eq. 1 is shown in Figs. 1 and 2.

3.2 Construction of Predictive Functions

Figure 2 shows how the price of natural gas has been adjusted to a line with an acceptable R^2 coefficient. It is worth emphasizing that increasing the order of the polynomial regression and improving R^2 will not improve the model. Moreover, while the order increases, the surveys usually become worse. Therefore, the analytical expression of this line is now the model followed by this price. This has been prospected until 2018 and it appears that there will not be a turnaround.

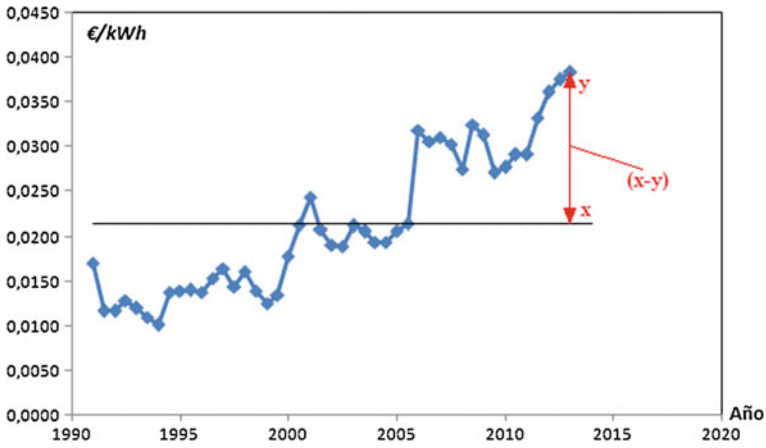

Fig. 1 Natural gas price. Standard deviation

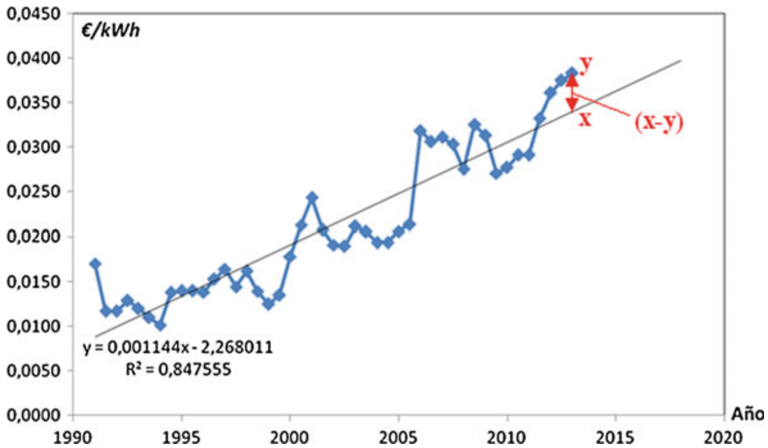

Fig. 2 Natural gas price. Measure of deviation from the model

However, this simple model can be supplemented with the dispersion. To do so, a normal distribution must be assumed for each year, centered in the prospected point with standard deviation calculated with Eq. 1. This idea is shown in Fig. 3. Thus, an assumption is being made that the most normal and the most likely scenario is that the energy price follows the mean of each distribution, thus adjusting to the model. But this assumption allows for the possibility that in some cases it can deviate from it. As seen in Fig. 4, such deviations do not exceed twice the deviation 95 % of the time.

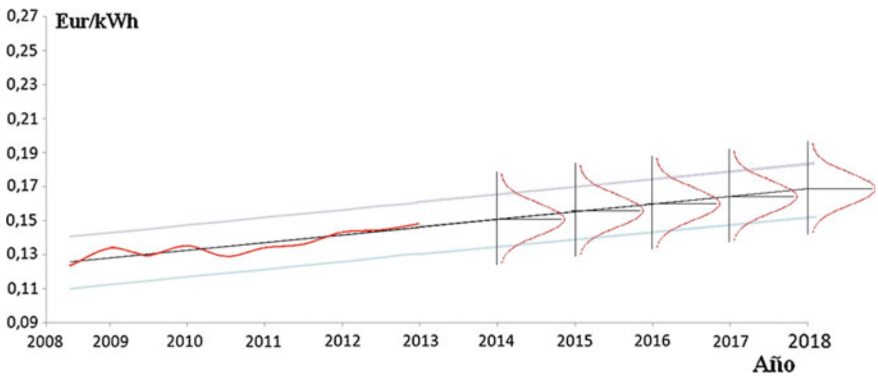

Fig. 3 Prospected electricity price with uncertainty. *Note* The *red line* is the price of electricity obtained from historical data, the *black line* is the model followed by that price, the *purple* and *blue lines* are model translations on each side to identify the area of 95 % probability. It is understood that for each year prospected there is a normal distribution centered on the value of the model and keeping the deviation throughout. The period used for the correlations of the models will depend in each case on the energy price studied

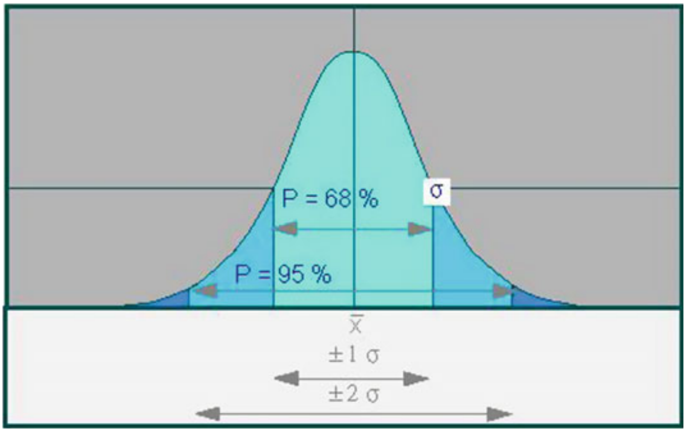

Fig. 4 Normal probability distribution

To be able to simulate a normal distribution, it is necessary to use random numbers. This topic, which is detailed in Alvarez (2011) and Rodríguez-Aragón (2011), will not be explained here, although it is important to emphasize that the best algorithms should be used to generate such random numbers, as the proper functioning of Monte Carlo depends on them.

When an algorithm for generating random numbers works properly and on a large number of occasions, it ultimately provides a uniform distribution of numbers, that is to say that all numbers are equally likely to appear. It is possible, using a conversion, to transform from a uniform distribution between 0 and 1 to a normal distribution. This conversion is shown in Fig. 5.

Therefore, the simulation system of an energy price is as follows:

- Generate a random number between 0 and 1 by an algorithm.
- Convert that number into the corresponding number through processing and the normal distribution of the energy.
- Repeat the above operations for all years to prospect for a scenario.
- Repeat the above operations to achieve an adequate number of scenarios that could be studied statistically.

A scenario is defined herein as the set of a simulation value for each prospected year. That means that a scenario is composed of one price simulated for 2014, one for 2015 and so on through 2018 inclusive.

At this point a distinction should be made between dynamic simulation and static simulation.

Static Simulation: is the simulation where each prospected year is independent of the simulation of the previous year in the same scenario.

Suppose that in the case of natural gas the aim is to obtain the price for 2014. In Fig. 2 it is shown that the price is 0.036005 €/kWh using the regression. Now to simulate uncertainty using Monte Carlo, the price can deviate. As mentioned

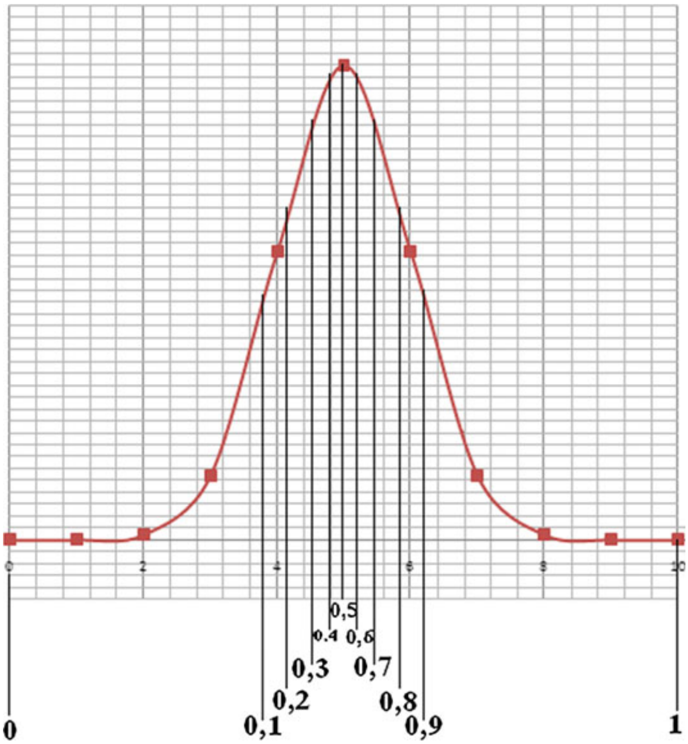

Fig. 5 Converting a uniform distribution into a normal distribution. *Note* The numbers below in bold are those obtained with the uniform distribution; they are transformed by equal probability into those that represent a normal distribution. For example, obtaining 0.1 with the uniform distribution, as well as getting 3.71 in the normal distribution, is 10 % probable. Therefore the 0.1 uniform distribution transformed is 3.71 normal distribution

before, the price will appear less likely the further it is from the expected price following a normal centered exploration. Suppose that in one of the simulations, the price is 0.045 €/kWh. This means that the price has increased considerably and would thus be a very pessimistic simulation.

However, if the aim is to obtain the price for 2015, then ie would not be taken into account within the same scenario that in 2014 the price skyrocketed. It could occur that the price for 2015 was €0.03/kWh, so after a sharp rise there was a very strong price drop.

This example highlights the need for the previous year's simulation to be considered in order to be closer to reality and to avoid very improbable predictions. This is why the dynamic simulation is needed.

Therefore, the dynamic simulation takes into account, within the same scenario, the price of the previous simulations to obtain the simulation for the corresponding year.

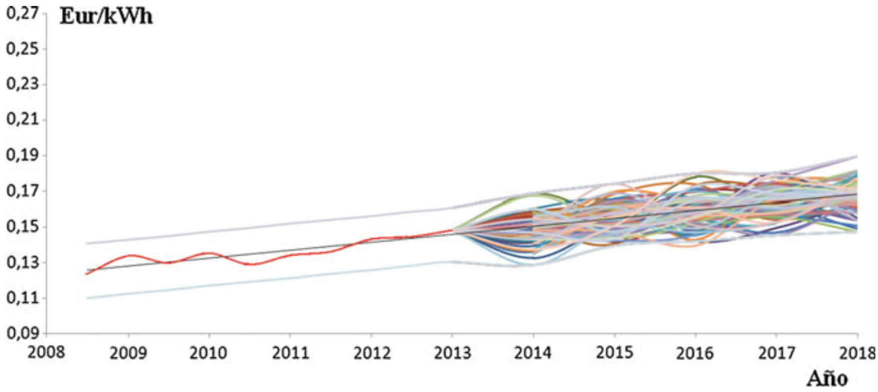

Fig. 6 Historical and prospection with 80 scenarios of natural gas prices

The static and dynamic terms refer to the regression. For static simulation, the regression is done for the set of past data and is not modified during the simulations. For dynamic simulation, the regression is done as in the static case but this time is updated with the simulated price obtained.

4 Results

The results of carrying out the above mentioned with one energy price are shown in Fig. 6. The calculations have been implemented in Excel since many authors recommend its use due to its easy and clear exposition of the development of calculations (Eckstein and Riedmueller 2002; Evans 2000; Faulín and Juan 2005; Andrew 2006; Gedam and Beaudet 2000).

The different scenarios calculate different prices for the same year. These functions as described in this work are the inputs to bigger Monte Carlo simulations for calculating large financial parameters of different EEM

If Fig. 6 is compared with Fig. 3, it can be checked that what was intended in each year has been achieved, since the distribution of prices has scanned possible prices according to the probability of them occurring.

5 Conclusions

In order to make important decisions about investments in energy efficient projects, it is essential to have reliable information on the uncertainty associated to the calculation of the traditional parameters of economic performance: PB, IRR and NPV.

The proposal of this work to present these parameters as probability functions allowed making a decision considering the risk associated with each project, thus improving the results of decisions.

Since these parameters are related with uncertainty about variables such as energy prices, the risk or uncertainty of a parameter depends largely on the uncertainty of the input variables, so it is necessary to model the probability functions input variables to obtain a result as a probabilistic function.

Once system entries have been modeled, a Monte Carlo simulation follows to model the probabilistic output functions or results through many simulations.

The variation that may occur in prices in a year has been calculated taking into account how it has changed in recent years regarding the tendency of the average price itself. This trend was obtained from a regression of historical data. This calculated variation defines the probability function of the price of that energy compared to the trend in a given year.

In projects that extend over several years, the most common types, which are the most common ones, dynamic simulation is closer to reality than static simulation. That is because the simulation data from previous years is taken into account to implement the simulation of subsequent years, adding uncertainty about the next year in the same simulation.

Taking into account all previously explained, there is a need to obtain real in-formation regarding energy prices in subsequent years, including the probability of the accuracy of the prices given. Thus, the inputs in the processes and choices made on energy efficient investment projects will be more accurate.

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Part VI
Rural Development and Development Co-operation Projects

Revolving Funds as a Tool for the Success of Rural Development Projects. Case Study: “Casa Campesina” Cayambe (Ecuador)

M. Maneiko, V. Montalvo and S. Sastre-Merino

Abstract A key element of sustainable rural development is to improve the welfare of communities so they can enjoy a decent and fair life, which cannot be achieved without an increase in their incomes. To achieve this, it is necessary that rural development projects seek to strengthen productive capacities and management of communities as well as successfully incorporate funding mechanisms to enable the sustainability of accomplished development. One of these is called a “Revolving Fund” for microcredits, which is an example of a funding mechanism that has been applied in rural settings to support entrepreneurs in order to generate productivity. To prove that these mechanisms are valid to ensure the sustainability of the improvement in the welfare of communities, this paper details the experience of Revolving Funds which were implemented in 1994 in the “Casa Campesina” development project in Cayambe (Ecuador) with $16.708, and that remain active in 2013, and have lent more than $4.000.000 of credits. A two-step research model was used which analyses the experience from both a quantitative (amount and number of credits) and qualitative (impact on beneficiaries) approach.

Keywords Revolving fund · Rural development · Sustainability · Microcredit

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1 Introduction

One of the most common problems, when starting a project or enterprise, is obtaining the financial resources for its implementation as well as for its functioning, especially when it comes to projects or enterprises in rural communities. The sustainability of developed projects, which initiate actual changes in the life of a community, is vitally important. Therefore, it is necessary that the local development projects seek not only to strengthen the capacities, production and management of local communities in which they are executed, but also to incorporate funding strategies to allow them to raise and sustain their development.

A lot of effort and resources have been used to develop microfinances as a tool to fight poverty (Hermes 2011). Microfinances play a significant role in many people's lives in all the continents of the world. Microfinance is a financial service which combines microcredit, insurance and payment services giving poor people an opportunity to access this kind of services to find the most suitable product to meet their needs (Ledgerwood 1999). These services are provided to low-income clients by Microfinance Institutions (MFI), which can be both commercial banks and non-profit organizations.

Ledgerwood (1999) describes "the goal of MFIs as development organizations is to service the financial needs of unserved or underserved markets as a means of meeting development objectives. These development objectives generally include one or more of the following: to reduce poverty, to empower women or other disadvantaged population groups, to create employment, to help existing businesses grow or diversify their activities, to encourage the development of new businesses." The microfinances are individual and group-based approaches; and are also split into direct and indirect targeting. (Tietze and Villareal 2003). Direct targeting is when credits are provided to a specific sector (agriculture, fisheries) or a certain group (the poor, specific classes or women) and indirect targeting means that products are available to a larger target group but they are designed in such a way that they will be attractive only to people in a smaller and more specific target group (Ledgerwood et al. 2013). For instance, a credit can have such conditions that only the poorer will find it appealing even if in theory it is available to everyone.

There are authors who support and criticize microfinances. The supporters, like Hermes (2011), say that they help to improve the economic situation for families; they may contribute to savings, improving nutrition, they may reduce vulnerability due to illness, drought and crop failures, and they may contribute to better education, health and housing for the borrower. They may also contribute to an improvement in the social and economic situation amongst women. Furthermore, Dunford (2006) asserts that using microfinances can be a way of accomplishing the first of the seven Millennium Development Goals.

There are also authors who criticize microfinances. Scully (2004) states that microfinances targeting women only partly empower them, they do not reach the poorest of the poor and they are not a real answer to unemployment growth. Levin and van Riemsdijk (2012), describe a tragic situation which happened in India in

2010, where 200 farmers committed suicide. This was related to them being indebted to MFIs and not being able to repay their loans.

Now many researchers are trying to find out if microfinance programs can actually reduce poverty and improve social and economic well-being amongst beneficiaries. Based on the bibliography, there have been many investigations carried out on impact evaluations that are proving the positive effects of microfinances in developing countries, for example, Ethiopia (Gobezie and Garber 2007), Uganda (Lawko 2006), India (Imai et al. 2010), Bangladesh (Mahjabben 2008), Thailand (Coleman 2006). In these cases they evaluated impact using qualitative or quantitative methods, or a combination of both, by choosing indicators like income growth, savings, and consumption, children's education, hygiene, and women's empowerment. In all these cases results have shown a significant impact on people's lives, which have improved because they have received loans.

However, each case is unique based on the different regions, cultures and people involved and the management of the projects. This paper will describe the impact of microfinance experiences which have been implemented since 1994 by the "Casa Campesina" Foundation in Cayambe (Ecuador). These experiences involved Revolving Funds that financed small credits (microcredits) for rural and indigenous families of the area. In this study information was obtained using a questionnaire, which was used for interviewing the beneficiaries of this project. Data shows that microcredits had a significant impact on the improvement of living conditions amongst the families who have received one.

2 Case Study Context

According to the World Bank (1995), in 1994 35 % of the Ecuadorian population lived in poverty. Throughout the years, the situation is improving and the poverty level in 2012 went down to 27.3 % (CIA 2012). This could have been caused by different reasons: emigration, especially affected by the crisis in the late 1990s that spurred a large exodus, where most people moved to the US, Spain or Italy (Jokisch 2007), political reforms, initiated by President Rafael Correa in 2007, which speeded up Ecuador's economic growth (World Bank 2014), and other factors. The World Bank (World Bank 2012) also states that Ecuador's GDP has more than doubled from 2004 to 2012 going from 36,591 (Millions of current $) to 84,039, with an average GDP growth of 4.7 % during that period compared to a global average of 2.7 % in the same period. During that time, the GNI per capita in current international $ has grown from 6340 in 2004 to 9490 in 2012. This data shows how the economy has developed in general terms in recent years. However, this general data doesn't show if the growth was the same across all parts of society.

Ecuador's economy is mostly based on the export of petroleum, bananas, cacao, coffee and other primary agricultural products such as shrimp, fish and wood (CIA 2012). Ecuador has four very different areas (Amazon basin, Andes Mountains, coast and islands of Galapagos) where the economy is based on particular activities.

This article is focused on the province of Pichincha, canton Cayambe in the Andes Mountains with a population of 83,235 inhabitants (AME 2014), where the most important income generators are agriculture, raising livestock, producing dairy products, and floristic activities. However, the economy can be impacted by different accidents and natural disasters that lead to extra help being required in order to achieve economic growth.

In 1987, the northern part of Pichincha province, in particular the canton of Cayambe was affected by an earthquake, which was so strong that it became a significant event in the history of the area (Ferraro 2004b). This disaster left many families homeless. This led to the emergence of the work of the "Casa Campesina Cayambe" NGO which operates under the responsibility of the Salesian Society of Ecuador. In April of 1994, it became the "Fundación Casa Campesina de Cayambe" (FCCC), a private entity under the responsibility of the Salesian Society of Ecuador, and also became a non-profit NGO (Misiones Salesianas 2010).

The following are amongst the FCCC's most important objectives (MACH 2013):

- Support indigenous communities in the cantons of Cayambe and other areas, in their efforts to improve their socio-economic conditions and their advancement, through the planning and execution of development programs at all levels.
- Develop activities to improve educational and health conditions of indigenous children.
- Provide the indigenous people with humanitarian, moral and spiritual support.
- Provide indigenous and rural families with places where they can spend nights, attend courses and have meetings.
- Enhance the promotion and integral development of the rural communities that are linked to the Foundation.
- Provide several services including medical, dental, educational, legal, and others such as training according to the needs of those coming to the Foundation.

To achieve these objectives it manages various programs: program for infrastructure, credit program, program for improvement and maintenance of production, educational program, childcare centres for indigenous children, Tainate Huasi occupational centre for professional education for young indigenous people, healthcare program and community radio station (Serrano and Ferraro 2012). The credit program is financed by a fund which has a rotary nature provided by the FCCC. In this study, the impact of the credit program on the life improvement of indigenous and rural families is analysed and evaluated.

The FCCC credit program purposes are (FCCC 2013): the credit program serves the needs of indigenous and rural communities of Cayambe and Pedro Moncayo; provide funding for productive and non-productive activities with affordable interest rates; provide funding to optimize and maximize the use of human and natural resources; contribute to the improvement of community organizations; respond to the specific needs of the population to avoid capitalization of Agricultural Production Units through the credits; promote new productive activities to improve household incomes; community organizations who are taking responsibility to pay the credit if a customer is unable to do so; respond to the needs of training and technical assistance requested by communities.

To meet these purposes the FCCC offers 9 types of microcredits (FCCC 2013):

1. Emergency credits. This type of credit is created to meet customers' immediate funding needs. They can access this loan despite having a valid regular credit. The ability to get credit depends only on the customer's credit history. The term of these loans is up to 6 months and the customer has to make monthly payments.
2. Microcredits. Intended for people with fewer resources to start productive enterprises.
3. Farming. Aimed at agricultural producers located in rural and marginal urban areas of the impingement area.
4. Ordinary loans. Credits are freely available to use to meet their immediate needs, either for productive or unproductive purposes. They are the most commonly requested, because they are not targeted at specific activities and users can decide how to invest the money according to their needs (Ferraro 2004a).
5. Urban population. Focused on enterprises created by the urban population (market associations, artisans, small businesses, etc.).
6. Transport. Focused on the acquisition of vehicles.
7. Housing. Intended for the construction, acquisition or rehabilitation of decent housing.
8. Partners of Salesian Society. For employees of the Salesian institution.
9. Group credits. These credits are targeted at groups of producers organized in communities such as: Women's groups, milk collection centre, etc.

The FCCC provides their service to the cantons of Cayambe, Ibarra, Otavalo and Pedro Moncayo. In all of these, people are organised in communities, of which Cayambe has more than 150. The Canton of Cayambe received 90 % of all the loans. The total number of credits given between January 1994 and March 2014 is 27,888, the FCCC's database shows that 8797 families could benefit from them and 43 % of them were granted to women. The average age of the recipients is 47 years old, which is relatively high. Table 1 shows how the total amounts of credits have evolved over the years.

Figure 1 shows the distribution of activities for which microcredits were granted. Infrastructure and livestock have the highest values; more than 15,000 credits were requested for these two activities alone. Data shows that there was a lot of investment in the improvement of infrastructure and buying animals. However, it could be the case that the money borrowed was not always used specifically for the purpose it was received. The FCCC does not ask for too many requirements, but even then they can ensure that the money is invested in the way it was intended for.

The yearly interest rate of microcredits is 13–15 % depending on the type of credit. There are only exceptions for construction, acquisition and renovation of houses for which the FCCC offers an interest rate of 5 %. The rate of interest for defaults is 1.1 % annually and they do not charge any other fees, fines or

Table 1 Evolution of lent credits during 1994–2013

Year	Number of credits	Total amount $
1994	452	16,708.38
1995	1436	56,778.85
1996	1286	120,683.10
1997	1153	121,152.50
1998	1259	204,344.50
1999	1286	335,962.16
2000	1557	612,791.32
2001	1462	891,648.44
2002	1790	1,348,642.83
2003	2009	1,789,073.08
2004	2151	2,506,321.92
2005	1913	2,946,829.87
2006	1879	3,073,114.72
2007	2247	3,972,059.64
2008	2113	4,368,135.47
2009	1974	4,747,071.39
2010	2262	6,461,170.67
2011	1870	5,700,553.81
2012	1672	4,668,312.02
2013	1449	4,176,243.44

Notes In the first trimester of 2014 the amount of credits already lent was more than 1 million dollars

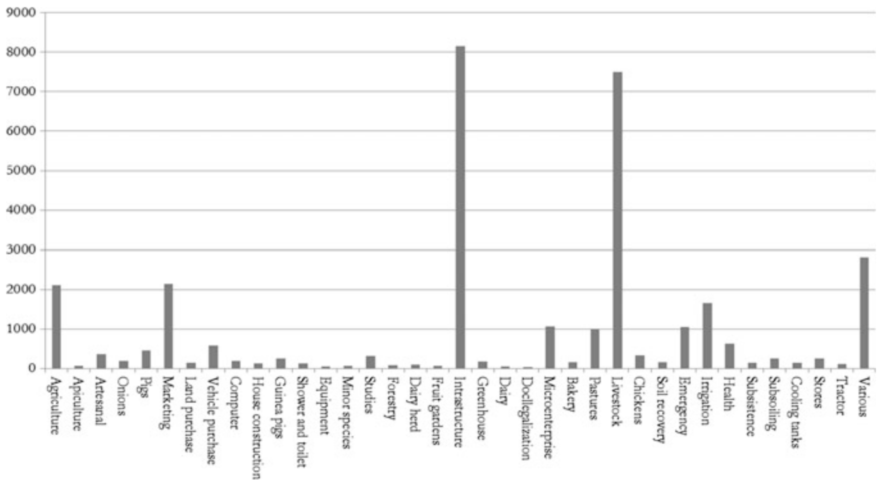

Fig. 1 Distribution of activities for which microcredits were granted during 1994–2014

commissions. This is one of the reasons why people prefer to borrow from the FCCC rather than other organisations or banks working in the area, whose interest rates are often almost double. Another important factor, which makes this program attractive to people, is the ease of achieving the requirements and the few documents they need to provide.

Requirements which clients have to meet in order to receive microcredit from the FCCC (2013):

- Be a member of the community or organization and have not been removed from it for failure to pay a loan.
- Application approved by the Assembly of the community or organization and supported by the leaders.
- Copy of identity card of the client and spouse.
- Original deed of the property, which is certificated by the institution "Registro Actualizado" (valid for 3 months from the date of issue). The FCCC asks for certification not as a guarantee of the credit awarded to the member but as proof that the person has economic resources to pay the debt; a deed may be applied for up to 3 members.
- Letter of authorization in case of not being the property owner and a copy of the owner's identity card.

Even though interest rates are low and it is easier to access credits, people still borrow from other organisations, the reason being that the lower amounts offered by the FCCC would not always meet the needs of the borrower. The total amount of each loan depends on how many times beneficiaries have already obtained them, and how well they paid previous debts, if any. For example, loans for farming, ordinary loans and for urban population have a maximum total amount of 2000 dollars the first time and with each further loan it increases by 1000 dollars up to 6000 dollars or more. The term to pay these debts can vary from 18 to 60 months. The payments are made preferably each quarter, but it is also considered, if there is a need, to make monthly payments. Each fee payment includes capital and interest.

2.1 Community and 'Deuda'

From the data above we can see that the FCCC has been successfully functioning for more than 20 years. One of the reasons for the foundation's success is that they require all the families wanting to get a credit, to be a member of a community organisation. The community can be defined in very general terms, as a group of families/production units with collective rights in a specific territory which they control and from which they enjoy usufruct, who collectively manages issues of common interest (such as water allocation, maintenance of electrical and irrigation systems), controls communal land, organizes collective work and eventually interacts with the "outside world" (Ferraro 2004b). The communication and decision making are done in regular (monthly, weekly—depends on each community) meetings. Meeting attendance is mandatory. During the meeting one of the issues they discuss is related to the credits: they ask which families will want to apply to get credits soon and mention families who have not paid their loans on time, known as 'morosos' (eng. defaulter). And if there are more than 6 families in the community who have not paid their loans on time, others are not able to get one until the debt is paid. This way they communicate and motivate each other. Morosos feel responsible to pay their debt as soon as possible.

Another important characteristic of the indigenous society of Cayambe is known locally as 'deuda', which literally means debt. Deuda is a relationship between two parties in which one gives something to the other. The recipient then pays this back in the future because of different reasons like a moral law or by obligations the subject has assumed (Ferraro 2004b). It is not reciprocity that creates a debt, but the debt establishes reciprocal relationships (Ferraro 2004b).

One of the founders of the FCCC Javier Herrán (2011) says: "At the beginning of the FCCC's microcredit program, it was considered as a tool for agricultural development, as an input. Over the years, reflecting on the experiences gained regarding microcredits and their implications, the concept of microcredit has become much more than simply a static "tool", and is now considered a dynamic system in the process, since it is inserted into the complexity of human development."

3 Methodology

This study's impact evaluation aims to measure if people, who have participated in the microcredits program, saw changes (economic, social, education, housing and etc.) in their lives.

Two-step research models are used in this study, which analyse the experience from a quantitative and qualitative approach. The quantitative approach was applied by analysing information provided in a FCCC database as well as the information provided by interview data like amounts, number of credits or savings put aside. In the case of qualitative methods, opinions and experiences were gathered from beneficiaries, which gave a more personal perspective on the impact they have.

This study has a limitation which has to be considered. It did not have a control group which could be compared with the treatment group. Hermes (2011) and Ledgerwood et al. (2013) analyse different approaches related to control groups and there is no unique way to perform an investigation. What matters most is the context. Therefore, in this case, to compensate this limitation, some questions were used in the questionnaire where interviewees had to specify things they had before and after receiving the loans, even if it is not the most accurate way to measure impact, but in this case it is not possible to do it any other way. This occurred because society had been so affected by microcredits, that in many communities there are no families who have not borrowed from the FCCC.

3.1 Hypothesis and Indicators

The main hypothesis of this work is that "Revolving Funds are valid mechanisms to ensure the sustainability of the improvement in the welfare of communities". The indicators used to check this hypothesis were: Education (Years of school completed; Current attendance in school; Children attending University), Housing (Number of people per room; Renovation/acquisition); Land and farm; nutrition; Incomes and savings; Community; Holidays.

These indicators were selected because of their usage as poverty indicators by the Consultative Group to Assist the Poor (CGAP 2003), Guidelines for Impact Monitoring and Assessment in Microfinance Programmes (Schäfer 2001) and analysing recommendations provided by the FCCC. One indicator which was added and differs from other impact evaluation tools is holidays. It was considered as an important indicator because indigenous and farmers from the mountain area were moving much more around the country and were coming to the seaside and holiday areas. A questionnaire was prepared using these indicators.

3.2 Sampling and Data Collection

In order to get preliminary results, the questionnaires were collected during two weeks in March 2014, by going to the group meetings organised by the FCCC, visiting the market in Cayambe, where a group of women who have received credits were selling their products, and approaching people coming to the FCCC office who were coming to pay their loans. The latter was the most effective for the quality of answers, but the most time-consuming.

To evaluate the impact of the microcredits on beneficiaries of the FCCC, 141 people were interviewed (unfortunately 25 questionnaires were rejected). To be able to see the biggest changes in the living condition of the families, interviewees were selected from those who have borrowed money for livestock, irrigation and agriculture, which is one quarter of all the credits taken since 1994. In addition, a group of women was interviewed, whom in the last years showed a lot of motivation and improvement in the organisation of their group. Out of the 116 people interviewed 41.4 % were male and 58.6 % were female.

4 Results

During this investigation 116 families were interviewed which in total involved 493 people, out of which 321 were adults and 172 were children under 18 years old. Amongst the adults, the main occupation was self-employment either in agriculture or in non-farming activity (32 %), 29 % are salaried workers, for example employed

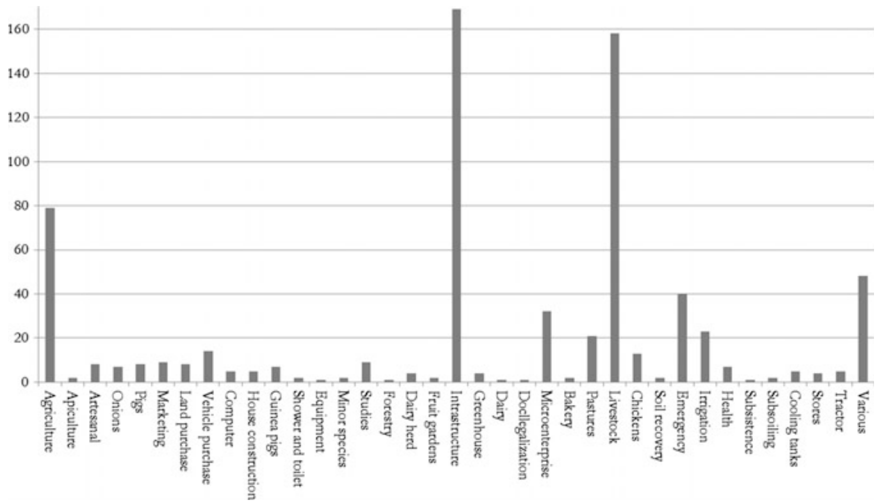

Fig. 2 Distribution of activities for which microcredits were granted to the people interviewed

in floriculture, 14 % are domestic workers, mainly women, 9 % are students and the other 16 % retired, unemployed or did not specify their occupation.

The people who have been interviewed have received 710 credits in total, which is 6.1 loans per family. Figure 2 shows the activities for which these families have borrowed, representing on average 3 % from the total number (Fig. 1) of each activity. Although the loans from the FCCC are easier to access and have a lower interest rate, people still borrow, in this case 49 % confirmed, from other institutions as well.

Interviews provided the following results about each of the above mentioned indicators.

4.1 *Education*

32 % of the interviewees said that microcredits from the FCCC had an influence on their children being able to attend university.

The study regarding education shows that 8.4 % of all adults have either no or partial primary education, 47 % have primary education, 26 % secondary education, 12.8 % technical or university degree and 5.9 % did not specify their level of education. These results demonstrate that in the society of Cayambe primary education is the dominant level of study among adults over 35 years and secondary, technical or university studies among young adults who are under 30 or in their early 30s. This proves that in the last years the importance of education has increased and younger people are willing to finish secondary school, as well as continue studying in universities. Further proof that education plays an important role in society is the fact that 100 % of school-age children attend classes.

4.2 Housing

Housing is another very important indicator for this investigation. 39.6 % of the families interviewed had improved their living conditions because of borrowing from the FCCC. 54 people confirmed that since they received loans they bought or built a new house and 46 acknowledged that receiving credit had influenced their ability to acquire their housing. The reasons that have been specified for getting a new dwelling were: the old one was too small for their family, there was a need to live separately from parents or there was an urgency for a new house.

Simultaneously, significant improvements were noticeable in terms of property renovations, where 70 houses were repaired since 2004, of which 75 % received loans for it. The most frequently mentioned repair works that have been carried out were pargeting or painting, changing or repairing roofs, building a second floor as well as increasing the amount of bedrooms, changing doors and windows, building showers and toilets, improving or introducing electrical networks and installing floor tiles or other materials.

Home improvements also consist of renewing equipment inside the house like buying kitchen facilities or obtaining a mobile phone, which for some people can seem like basic gadgets, but for people with lower incomes it can mean an improvement in their quality of life. Therefore, it was found that 29 % of those interviewed have obtained a mobile phone after they borrowed from the FCCC. 24 % of the families have equipped their dwellings with fridges, stoves and TVs.

Finally, equally as important with regards to housing is how many family members have to share rooms. The calculations show that the average for all families from the study is 1 person per room, but 56 % of the families have more people per room.

4.3 Incomes and Savings

These are the two most difficult indicators to measure the impact of, as in this case it was not possible to compare with non-clients. Incomes and savings can be affected by various factors, like economic changes in the country, sickness of family members, loss of employment and others, and can change over the years. However, 72 answered that their incomes have increased and 73 also confirmed that they had a chance to have some savings. Even though it is self-evaluation, it is still valuable information, which gives an idea of how people view the improvement to their livelihood.

4.4 Land and Farming

As previously discussed, the economy in the Cayambe area is based on agriculture. For this reason it is a relevant indicator. The information, obtained from the FCCC's customers, shows that 101 families have land, of which in 82 cases is capable of being cultivated and in other cases is used for grass growth to feed animals. The size of the land varies from very small (100 m^2) to very big fields (24 ha), and with the support of the loan 27 families could acquire more land.

The canton of Cayambe is well known for its dairy products. For this reason many farmers grow cattle as well as other animals like pigs, chicken and guinea pigs. 86 people answered that they grow animals, both for self-consumption or for selling, which is 74 % of all the people interviewed. 70 people confirmed that they had incomes from selling animals and 67 received incomes from selling animal products (milk, eggs, etc.). In the case of cattle, an important installation is an electric fence, which helps to define the area of grass which animals can access. The participants of the investigation were asked if they obtained this tool after they received a loan from the FCCC and 22 answered positively. This demonstrates that not only is it important that they buy animals, but it is also critical that they improve their farms.

4.5 Nutrition

Ecuador has very rich land for growing vegetables and fruits, which they export a lot, but also use for local consumption which means that they do not suffer from hunger, as is the case in other countries. The only problem that can occur is that their diet is not adequate, because of a lack of variety of food or consumption in large quantities of less nutritious food, like fried food. It was established that receiving credits did not affect their nutritional habits. Some respondents answered that they can buy more processed food (mayonnaise, canned food, candies, etc.) from shops, but it is not necessarily an improvement in nutrition, rather it explains that people simply have more resources.

4.6 Community

Communities in Cayambe play a significant role in people's lives. They meet each other on a regular basis, they work together to improve their surroundings and also depend on each other for being able to receive credit from the FCCC. The advantages that microcredits provide are not just material. It is also a way of keeping society united; it highlights the importance of team work and develops responsibility amongst its members. As the community members are so connected to each other they see how lives are changing for their neighbours and 89 have answered that they have seen noticeable developments in the last 10 years in the neighbourhoods they live in. The improvements which were commented on the most were the installation of phone lines, street lights, tubes for drinking water, sewerage, built roads and an increase in people's own businesses. These are the major changes, but it is likely that there were many bigger or smaller projects, which have changed and improved the surroundings for rural people. In people's opinions, these improvements were influenced by the microcredits they received. Only 8 responded that life in the communities got worse or did not change during the years. The reasons stated were that their community leaders do not do their job properly in order to improve conditions. All the families who participated are living in 78 communities. This gives a good overview of how communities evolved during the last decade.

4.7 Holidays

As mentioned above, holidays were selected as an indicator to see major improvement in the lives of rural people, as it is not considered as a basic need, but more as a sign of luxury. Families were asked if after receiving credit they could spend holidays away from home and 27.8 % responded positively. There were also some respondents who could afford holidays, but taking care of the farm does not allow them to leave the house for a long period of time.

5 Discussion

As demonstrated by the results, in one way or another, the living conditions of the interviewees has changed. It is important to acknowledge that these results are not simply due to the fact that people in the town are able to receive microcredits from the FCCC. It has to be considered that they were also strongly affected by the country's economic growth. However, results presented in this paper provide relevant proof that microcredits, handed over within the FCCC's framework of revolving funds, had a significant impact on the improvement of life for people in Cayambe. Firstly, the FCCC has worked in the area for almost 30 years and people come back to borrow; they finish paying their loan and come back again for another one, because it gave them progress and the possibility to move forward. It can be seen as a lifestyle for economic growth.

Even though there is no comparison with a control group, it should be taken into account that most of the communities have acknowledged the lack of people who have not requested microcredits. This makes it impossible to create a control group but it also demonstrates the acceptance the microcredits project has in the community. Moreover, it is clear that the perception amongst borrowers is that microcredits are helping their lives, that their lives have improved and that one of the reasons for that has been receiving microcredits.

There are more people who seek higher education than there were a few years ago. Some families are now able to go on holidays which is something they did not consider before. Some families have acquired more land or improved their farms in one way or another. Many families have also improved their house either by repairing it or by moving to a new house. And what is also very important, most of the people interviewed believe that the microcredits are one of the important reasons that made these improvements possible. Only a small proportion of them believes that the communities have become worse since then and, even in these cases, they believe that the reasons for the community not growing is not the existence of the microcredits but the lack of leadership by the community leaders.

Another point that should be considered is that Ecuador has significantly grown over the last years. This could make us think that the development of the region is mainly caused by the general growth of the country. However, this growth does not necessarily mean that all the regions of the country could benefit from it as perhaps they could, for instance, meaning that urban areas develop much faster than rural ones. At this point, it is important to mention again the perception of the different communities of Cayambe that the microcredits are one of the tools that have empowered them to improve different aspects of their lives. It is difficult to measure how much, but analysing the results it is clear that microcredits are actually helping the families in the region and that they keep seeing it as a tool that can help them to grow further.

6 Conclusions and Recommendation

The Revolving Funds for microcredits are a valid tool for sustainability in order to improve the welfare of its beneficiaries. It cannot be assumed that they are a tool that has a positive impact without first analysing the results. Although this is a preliminary study, it shows that the community of Cayambe has improved during the last years in different ways.

Even though a deeper analysis could be recommended in this case, this preliminary study already shows that microcredits have had a positive impact on the development of the canton of Cayambe. As well as other services which the FCCC provides, like the infrastructure program, program for improvement and maintenance of production, educational program, Tainate Huasi occupational centre for professional education for young indigenous and heath program. The general improvement in the country's situation has of course also helped, but the microcredits provided by the FCCC offer families of the region a possibility to invest that they would not otherwise have had. It is clear that there are improvements in many aspects and some of those improvements could have been difficult to achieve without the possibility of obtaining credit.

The FCCC's microcredits program has been accelerating development in Cayambe, but there is still room for improvement. In this case, two factors can be improved. The amount of the credits could be raised taking into consideration the beneficiaries' history of previous payments. Another point is the age of the recipients, as it is quite high; the average age is 47 years old. This is due to younger people having higher insolvency risk. This means that for many young people, the possibility of having finances for investments is out of reach.

The development of rural families is an important matter in this study. As well as the success of the FCCC, which is not only that it has been operating for almost 30 years but it continues to develop and grow (in 1994 it lent credits for $16.708 and in 2013 it remains active and lent more than $4.000.000). We can conclude that the Revolving Fund for microcredit implemented by the FCCC in 1994, is still in force almost 30 years later and supporting Cayambe's communities.

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Part VII
Training in Project Engineering

Planning and Projects: Three Visionaires Friedmann, J., Trueba, I. and Ramos, A

A. Cazorla and L. De Nicolás

Abstract It is impossible to talk about planning as a scientific meta-discipline without mentioning one of the most influential worldwide figures in the second half of the twentieth century: John Friedmann. His contribution to the planning concept on his *Planning as Social Learning* theory is still very relevant. This paper shows the intellectual connection between Friedmann, Angel Ramos and Ignacio Trueba, two of the Spanish intellectual drivers in the engineering project knowledge area, who contributed to the foundation of the Project Engineering Spanish Association. The three of them share a broad vision of the project and abandon the "blue print" planning model. They also see the project as a transformational tool that requires a different planning style to the one which prevailed in the 70s—both in public and private domains. They were pioneers in structuring Knowledge/Action in a different way, both in academic institutions where disciples helped to bring about change—and with direct action via projects.

Keywords Projects · Planning, social learning · Knowledge/action · Three visionaries

1 Introduction

Planning and Project concepts are deeply linked both, at public and private domain. They come together in relation to what could be called "operability" and are also intertwined in the context of Academy as they share teaching and research lines. The relationship between Plans, Programs and Projects is traditionally included in

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Fig. 1 Trueba et al. (1995)

the curricula of technical universities. The project is the operational tool of Programs and Plans (Fig. 1).

Manjón said, in a way that reflects the flavour of tradition that remains alive (De Arce 2002):

> The best teacher is not the one who has more knowledge, nor the one who gives more lessons, but the one who better educates, that is, the one who has the special gift of helping students to become women and men owners of themselves and their skills; the teacher who associates his work to his students' work and guides them to participate of the benefits of their knowledge.

Professors John Friedmann, Ángel Ramos and Ignacio Trueba, belong to the group of relevant innovative people within the Planning and Projects domain who, from their university departments, were able to create new ways of thinking and acting.

In the words of Ibáñez Martín (1995)

> The word style comes from Latin and Greek and means the stiletto which was used to mark letters in the boards covered with wax that preceded the paper. And, alike any writing machine – according to detective novels – has its own identification marks, such stilettos had also theirs, which enable to discover the author of the texts. This is why style no longer means the material tool, but the idiosyncrasy, the personality, the specific way of seeing things that a person or a type of person has.

Since the beginning of the Department of Urban Planning at the University of California, Los Angeles, created by Professor Friedmann in 1969, a new thinking around planning started, of which academics from the five Continents have benefited; Ángel Ramos and Ignacio Trueba initiated the Project and Rural Planning Department at the Technical University of Madrid in 1985. Since the very beginning, they contributed to the creation of the Project Engineering Spanish Association (AEIPRO: Asociación Española de Ingeniería de Proyectos) and promoted periodical meetings that, with time, became the International Congresses of Project Engineering, its XVIII edition held in 2014.

Julián Marías said he was convinced that the intellectual affiliation worked in the opposite direction as the biological one. The latter, he said, is proclaimed and acknowledged by the parents, who claim the paternity over their sons, while in the case of the former it has to be the son one who publicly acknowledges the parent and admits the debt with the master, showing the influences he has received and have led him to be the way he is (Carpintero 2008).

The common trends of thinking of the three professors are analyzed below and can be summarized in three concepts: *Modern Project, Environmental Claim and Knowledge/Action in Postmodernism.*

2 Key Starting Concepts of the Three Professors

The idea that the scientific knowledge about society could be applied to the improvement of this very society was developed, at first, in the XVIII century. By that time, it was widely believed that the thinking derived from any worthwhile valuable idea had to be practical, and its consequences should be measured with a rigorous mathematical method (Friedmann 1987). Modern utopian ideologies considered science, technology and planning as infallible tools to the rational control of nature and society (Llano 1988). These ideologies, despite their differences in different countries, have a common philosophical root that has been called postmodernism (Spaemann 2004).

2.1 Modern Project and Its Influence in Engineering: Blue Print Model

In the Modern Era, planning was seen as something linked to power (Schumacher 1976). The so called Modern Project is associated to this concept of planning—blue print project—and is based on engineering and scientific rationality with top-down approaches: blue print, is a top-down-approach linked to an objective and reductionist rationality with deep roots in the fields of engineering and construction (Bond and Hulme 1999). From this approach the first models of development planning were designed (Mannheim 1949; Lindblom 1977; Etzioni 1968).

The influence of Saint Simon (1760–1825) was clear in the vision of this Modern Project, contributing with complementary approaches to scientific Planning. Saint Simon suggested an image of society in which “Scientists and Engineers”, as the people most aware of organic laws in society, should draw the future according to a global plan (Friedmann 1987).

This view was inspired by the sciences of engineering and by the idealism of engineers who were under Saint-Simon’s influence, (Wolf 1981) and implied important consequences in the vision of humankind and its relation with nature, influencing the early development models and the classic engineering projects (Hayek 1955).

This planned strategy of society was called Social Planning within the Modern Project, in such a way that “every man is an individual belonging to a social organism to which he has to be subjected and should be satisfied with the generous advantages that enjoys as part of the current system, which is firmly acknowledged as the best of all possible" (Ramos 1993).

2.2 Modern Project and Its Influence in Engineering: Blue Print Model

The peculiar dignity that modern thinking attributes to humankind comes directly from the idea of dominance. One of the consequences of this approach was the awareness that "modern project does not consider caring and respecting nature; these issues are not so important in the light of efficiency and utility (essential laws that should not be interfered); solidarity with nature does not exist because nature has to be dominated".

Environmental Claim questions, with lights and shadows, if the technical progress, which has been undoubtedly reached, considers the ethical progress of humanity.

Figure 2 summarizes a workshop that took place in Cervera de Pisuerga (1984). The figure shows the view of Ángel Ramos who considered a comprehensive vision of what had been the relationship of humankind with nature and saw in the future the knowledge—Know How—as the understanding of nature that would go beyond what had happened since the XVII century (Cazorla 1999).

The idea is to find a solution to what Schumacher claimed: "it can be said that the modern world that has been modelled by technology stumbles from crisis to crisis" (Schumacher 1976).

Among other visible signs of damage, Schumacher highlights the deterioration of the soil where the action of humankind takes place. In this context it makes perfect sense the view of Ramos (Cazorla 1999) who pointed out the historic break in the idea of progress that has been present during the second half of XX century. A turning point from which a new Project, which claims respect for nature as part of

KNOWLEDGE IS KNOWING	(till XVII century)
KNOWLEDGE IS POWER	(XVII – XIX centuries)
KNOWLEDGE IS DOING	(XIX – XX centuries)
KNOWLEDGE IS HAVING	(second half of XX century)
KNOWLEDGE IS MANAGING	(end of XX century)

The future is to come back to "knowledge is knowing" with some nuances. Centuries of "contemplation", a few centuries of "exploitation" turning to "management" (an economic variable)

The nuance consists on "KNOWING IS UNDERSTANDING"

Fig. 2 Ramos (1984)

the real concern for the lives of the people who currently inhabit the planet and will inhabit it in the future, should start.

That reflection allows to state two key elements of the conceptual process that is being described: first, the project that claims respect for nature, and second, the condition of living condition of people now and in the future. Trueba (1995, 2002) identifies the connection between these two elements when, referring to Ángel Ramos, says: “His knowledge on natural resources, his scientific and research concern and, above all, his colossal sensitivity and respect for nature have contributed to my education” (Trueba 2002). As a consultant to FAO for several years, combining this work with his position as Professor of Projects at Technical University of Madrid, he had the opportunity to actively participate in the design of new methodologies for projects that FAO would launch in the 70s (FAO FAO 1991) and that would then be adapted to teaching an business domains, aiming to promote a new concept of Project that considers the respect for Nature and integrates it in the future business decision making process (Trueba 1995).

2.3 Knowledge/Action in Postmodernism: Elements of a New Project

As it has been stated above, Modern Project is reluctant to abandon old views and Environmental Claim calls attention to the crisis of the system. This section intends to initiate the intellectual building of a new Project framed in an emerging postmodernism and considering the key elements that, according to our three visionary masters, should be included.

The word postmodernism appears, by the first time, in the book of Toynbee *A Study of History* (Toynbee 1987) referring to a swift of paradigm with regard to modernism. As it has been described above, it appears as a reaction to: the failure of technocratic modernism, the idea of an endless progress, and the setback caused by the environmental claim that postulates the search of a lost balance (Cazorla et al. 2013).

Since the beginning of the 90s, different authors highlight the emerging of this postmodernism as a new cultural and ideological approach with other values and trends that claims new ways of thinking and acting in increasing contrast to the dominant trends in the past (Ballesteros 1989). In this new Era, the lack of novelty of the industrial and capitalist society, which turns into an “old” society, becomes evident. Some authors refer to this shift as *postmodern sensibility to difference* (Cloke et al. 1991; Philo 1992).

As the traditional concept of planning has been deeply linked to the so-called Modern Project, also called Euclidian Project, one of the intellectual temptations that emerged was synthesized in an “Euclidian or nothing” trend (Cazorla 2006). A way to solve this matter was the definition of Friedmann (1987) of the Planning concept as “the professional practice that specifically searches to link ways of knowledge with ways of acting", that this author proposes in a relevant paper which was awarded as the best of the year in USA (Friedmann 1993). This definition leads to conceive planning as something different to engineering where means are efficiently related to ends and projects draw the course of action.

Where the balance between the need of developing Projects from a non-Euclidean concept of planning can be found? What knowledge/action would be valid in this postmodernism context? To properly address this questions, it seems relevant to turn to Aristoteles and the interpretation of Llano (1988).

The acting has not always been right as can be seen by the generated model. It should be clarified that the assessment of actions as good or bad actions is not a result of the actions themselves but something constitutive of them. The purpose of doing and acting has different nature. The purpose of doing is to reach a product, while the purpose of acting depends on the agent. Aristoteles leads us to the conclusion that the good praxis is an end in itself. The praxis—human action—does not search, unlike the production, the perfection of an external work, but the perfection achieved by the agent (Llano 1988).

The recovery of the real concept of action in this new Era has a first component of a new style of planning that affects the relations of people with both, nature and other people, and leads to say that "what is not fair to Nature cannot be, at the same time, optimum and functional" (Spaemann 1983). In other words, "we shouldn't do all what is technically possible" (Ramos 1993).

Within the action, the notion of care is included by Llano as another key concept in the context of the new postmodernism sensitivity: "the rationalist and unidimensional attitude of dominance should be replaced by the original unity of contemplation and action that characterizes the care (epimeleia)" (Llano 1988).

In line with the approach that Friedmann (1993) described in the already mentioned paper and with Alejandro Llano, Ramos (1993) writes about *care* as a guide concept for action: "care never acts arrogantly nor intends to aggressively break into reality".

The care concept, at operational domain, corresponds the term respect in the framework of knowledge. Millán Puelles said: "Respect for Nature is also a natural human need, a primary need of our way of being which satisfaction appears to be valuable by itself" (Millán 1984).

The synthesis is that we can move forward. Figure 3 shows that the restructuration of coordinates in the operational context will lead us to an integrated vision when formulating projects (Trueba 1995) which will result from a good doing, but with a deep approach of respect, based on knowledge and care intrinsically linked to action. Bringing this postmodern sensibility to a postmodern planning model requires consistence—values—that enable to discover and redesign vital areas that take into account participation and commitment, these being understood as "the personal contribution" of every agent involved in the Project (IPMA 2010).

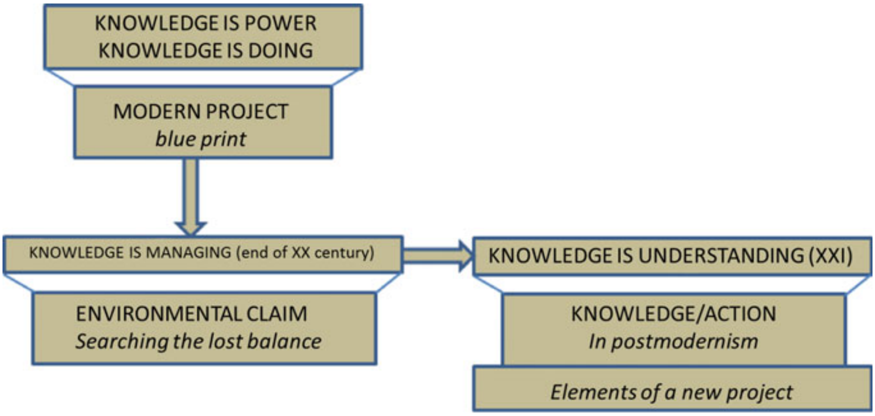

Fig. 3 Thinking from the three professors

3 Friedmann, Ramos, Trueba: Their Specific Intellectual Contributions

The previous section has been devoted to set the intellectual background of the three authors. Their particular contributions to the field of Planning and Projects follow.

3.1 John Friedmann: Planning as Social Learning

The Social Learning concept appears in the international literature as a way to develop an alternative Planning concept to the existing planning models in public domain. In 1973, Friedman published a book entitled *Retracking America: A Theory of Transactive Planning*. The book caused a truly intellectual shock in the North-American academic environment. It proposed a new system that would replace the bankrupted model that the American post-industrial society was facing. The book criticizes Allocative Planning, in force at that time, which dealt with the distribution of a number of scarce resources among different beneficiaries, and advocates for an innovative management planning, with a key element: the personal relationship that should exist between expert and customer (Cazorla 2001).

The epistemological process developed by Friedmann from then on, continues being explored in its wider ramifications. Karl Popper sees science as a matter of refuted hypothesis that become stronger when they resist the testing. Conversely, Friedman feels that, in the case of social practice, the contrary should occur. The role of the planner is not, in any case, the building of theories, but the innovation of society. The planner should be the professional responsible for mobilizing resources and bringing together public and private energies to achieve innovative solutions to the challenging problems in the public domain (Friedmann 1993).

The processes of Planning as Social Learning are based on the idea that any effective learning comes from a real experience of change. The population involved in a Project actively participates in the Planning, by means of their own behavior, attitude and values that generate actions addressed to join their experienced knowledge (Hulme 1989) to the planner's expert knowledge providing a mutual learning (Azgyris and Shön 1978).

The respect for the people involved—working with them—has enabled to develop methodologies of participation, negotiation and deep ethical approaches resulting in relevant professional and academic success (Cazorla 2013).

3.2 Ángel Ramos: Physic Planning and Projects

Friedmann became the director of the Urban Planning Program at University of California, Los Angeles, in 1969. It was then when his practical experience as a consultant of governments and institutions in different countries was consolidated in lessons that benefited students from the five continents. A similar journey was made by Angel Ramos who during the 60s developed an intense professional activity, related to the environmental restoration in civil works, and became professor of the Chair of Physic Planning and Projects in the Faculty of Forestry at the Technical University of Madrid in 1971. As a professor he devoted all his dynamism to train professionals and researchers seeking the balance between the aggressive technology and the preservation of the environment widely claimed by environmental groups (Fernández-Galiano and González Alonso 1999).

His reflections of those years shaped a very relevant publication, *Physic Planning and Ecology*. This publication continues to be an unavoidable reference for management of the natural environment to this day.

Angel Ramos is, together with Ramón Margalef and Fernando González Bermúdez, a visionary who introduced a new way of thinking, doing and developing human actions—Projects—in Nature.

> The practical translation of this new approach faces important difficulties…. The unavoidable need to satisfy, in so many fields, human needs and, therefore, continuing to develop projects is one of the main ones. Some radical views seem to overlook this reality. Analogously, the economic growth focus ignores the side effects of a Project. (Ramos 1979)

Friedmann promotes a method of working with people by means of crossing expert and experienced knowledge. Ramos is committed with a dialogue with Nature "be able to see, be able to appreciate, be able to give value" promoting a sustainable development which is rooted in the acknowledgment of biotic and abiotic variables that make it possible to find "the difficult equilibrium point that, many times would not be in one of the ends neither would be the mean point". Facing reductionists at both sides, Ramos contributes with an integrated view of the problems and the solutions addressing emergencies and trepidations, deadlines, and projections in time (Ramos 1993). Nature should be respected. Nature has her own physiognomy and a previous destination: this is why it is important to discover, in that quiet dialogue, the natural rhythms and, at the same time, to develop projects that integrate such valuable information.

3.3 Ignacio Trueba: Project and Rural Planning

Ignacio Trueba became professor and head of the Chair of Engineering Projects in the early 70s. By that time, he had already developed a vast professional work both, in public domain—participating in the formulation of the so-called Provincial Plans in the previous decade—and as consultant to FAO and the World Bank of UN. He continued his work in the Projects and Planning Department at the University of Madrid that was created during the 80s, as a consequence of the new organizational strategy of Spanish universities (Trueba 2002).

That professional experience happened to be very useful to advance on methodologies for formulation and evaluation of projects from a wide interpretation of the concept of Project that "involves many more disciplines than just technology and includes the economic development, social policy and environmental preservation fields" (Trueba and Morales 2011). This "way of seeing" projects in a broad sense leads to a systematic decision making process known as the Project Cycle. "Alike all living things, the Project is born, grows, develops, produces fruits and dies. It has a vital cycle". (Trueba 1982, 1985).

The concept of Rural Planning linked to projects was an innovative intellectual contribution that was several years ahead of what the European Commission would call Community LEADER Initiative (Liaisons Entre Activités de Développement de l'Économie Rural), to promote rural development through projects and implementing methodologies of social participation and respect for the environment that is still valid today.

The role of rural communities as actors of their own development by means of bottom/up methodologies, enabled to carry on engineering projects that conform and develop rural territories, connecting their traditional technical-economic component with other components already mentioned (Cazorla et al. 2013).

4 What the Three Visionary Masters Have in Common: The Values of the Planning and Project Professional

To frame this section it seems appropriate to recall an essential metaphysical feature. Since Aristotle, there is an intellectual agreement on the fundamental "modes of being" and their nine accidental types, also known as predicaments or categories.

As the being is reflected in knowledge and language, that "modes of being" correspond to different types or sorts of predicates that can be attributed, hence the name of predicaments (Alvira et al. 2001). All accidents infer the substance: the being of a subject. Besides, every accident has its own essence, which conditions the substance in a particular way (Alvira et al. 2001). Among the nine accidental types, some are called extrinsic because they don't affect the substance itself but only infer externally: the position (situs), place/where (ubi), condition (habitus), time/when (quando). There are other accidents that do affect intrinsically the matter: among these, we focus our research in the accident called relation.

4.1 Relation: An Essential Category of Substance for Action

The relation is an accident whose nature consists on the reference or conformation of a being towards another one. The key of this accident is something like abandoning oneself and going towards another. The very reality of this relation is, therefore, extremely weak and imperfect as it constitutes a pure "respect for" (Alvira et al. 2001).

So far our reflection to shows how this metaphysical background influences our three visionary Masters. Even though its reality is very weak, the scope of the relation accident is important and constitutes one of the key features that can be found as common to the three authors.

Human-Nature relation (Ramos), Expert-Experienced knowledge relation (Friedmann) and Urban-Rural relation (Trueba), are cohesive concepts meaning that *knowledge is knowing* how *to relate*. These concepts have been analyzed above and they have a common basis: humans and their actions with their peers (Friedmann), with Nature (Ramos) and with spatial contexts (Trueba). On the grounds of this basis the three authors intend to change reality according to a deep sense of how such reality is.

4.2 Planning Professionals and Projects: Some Inspired Principles

Through the reading of these pages a distinct element of the three Masters is expected to become clear: their professional performance in very different environments. In the case of Friedman as international consultant; meanwhile, Ramos worked in a company devoted to the restoration of landscapes; and Trueba combined works as public manager of plans and programs with works as international consultant to FAO and the World Bank. After intense years of work they became university professors and occupied relevant positions which enabled them to provide brilliant intellectual contributions linked to their living and experienced reality in a very dynamic cultural context. Some inspiring guide principles for professionals of planning and projects, who are immerse in the postmodern context are mentioned below. Llano, in his book *The New Sensibility* (1988) provides a synthesis of the thoughts of the three Masters.

Principle of solidarity. The Modern Project has created incompatible social spaces, while a postmodern Project claims social compatible domains, prioritizing solidarity spaces that have their most solid foundation in the dignity of people and are projected in the "care and respect for nature, living things, and landscapes that extend beyond themselves into the human condition" (Ramos 1993).

Trueba (2002), resumes that thinking when he writes: "a global solidarity, to remind us of our commitments every day and to promote an action for rural development based on freedom, is needed".

Principle of integrity. Although the challenge of interdisciplinarity seems to have been conceptually assumed, there is room to develop a field that was initiated by the thinking of Ramos, Trueba and Friedmann. The latter conceptualized a relevant term when he expressed that planning entrepreneurs are mobilizers of resources that seek to bring together public and private energies to solve public problems. But such planning is not addressed to seek benefit, but to obtain special values. Its intention is explicitly normative (Friedmann 1992).

It appears here, with its full meaning, the integrity with its "integral" dimension taking into consideration the values—ethical rather than technical—in such a way that, those planners should justify their action in public domain as that which causes human promotion and diversity—also ecological—in the global world (Friedmann 1993).

Principle of complementarity. We conclude with Llano (1988), who facing the dominant strategy of conflict—which confuses what is different with what is contrary—promulgates another way of thinking that is not exclusive, but inclusive, and defends the complementarity of the differences. There is not better complementarity than the spatial one, where the rural world is presented as a balancer of an urban world that has generated more harmful consequences to the environment in general and to humans in particular.

5 Conclusion

As a conclusion, it can be said that our three visionary Masters knew, without explicitly formulating it, to develop a thinking in the principles that have been mentioned. But, above all, and connecting with what was said at the beginning of this paper, they were able to see it and teach it to future generations that today develop this thinking in a natural way. In the words of Santiago González Alonso (Cazorla 1999) referring to D. Ángel Ramos, "as a treasure received almost unnoticed, by *osmosis*".

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