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

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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 19th International Congress on Project Management and Engineering. They are a good sample of the state of the art in the fields of Project Management and Projects 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 steps 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 non-profit 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 with the fields of action. At present, it is the Spanish Association Member of IPMA (International Project Management Association), an international association that brings together more than 50,000 project management professionals and researchers from 66 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 nine parts:

- Project Management
- Civil Engineering, Urbanism and Urban Planning. Building and Architecture
- Product and Process Engineering and Industrial Design
- Environmental Engineering and Natural Resource Management
- Energy Efficiency and Renewable Energies
- Rural Development and Development Co-operation Projects
- IT and Communications. Software Engineering
- Safety, Labour Risks and Ergonomics
- Training in Project Engineering

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

Valencia, Spain
October 2016

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Part I
Project Management

Comprehensive Reorganization of Project Management: A Case Study

Unai Apaolaza and Aitor Lizarralde

Abstract At the starting point of the present study stands the need to improve the Project Management (PM) of a company. The fundamental aspects of the implementation of the Critical Chain Project Management (CCPM) method and its implications for the organization are described, focusing on the changes and improvements achieved during implementation of phase 1. The analysis highlights a number of aspects revealed as a result of the implementation of the method beyond the quantitative results. The present findings are interesting from a dual perspective: their inherent value as knowledge and basis for future research; and, furthermore, the fact that they led to the need of a second phase, transcending the scope initially established by the project.

Keywords Project management · Portfolio management · Critical chain · Team · Resource management

1 Introduction

The relevance of PM nowadays seems to be obvious, considering the different arguments provided by several authors. Projects are the means by which strategies are performed (Cleland 1991), the innovation strategy of a company is implemented and developed (Tatikonda and Rosenthal 2000) and new products are developed and launched (Cook 1998).Thus, PM has been evolving since the mid-20th century, becoming a mature discipline in which nevertheless the interest is still growing (Bredillet 2010).

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Regarding PM research, some authors claim that it is still in its early stages (Sauser et al. 2009). Furthermore, a different approach is asked for by different authors, instead of that provided by the traditional PM research perspective (Ivory and Alderman 2005; Cicmil 2006). In particular, a more practice-focused research is considered necessary in order to reach a deeper understanding of PM (Blomquist et al. 2010). In this way, Sauser et al. (2009) suggest a new point of view beyond the *good versus bad management* perspective. In its place, it should be aimed to determine whether the management was right or not in any given particular situation.

One of the PM-related areas that have received more attention in recent years is the Project Portfolio Management (PPM). The interest in this area is due to the fact that most projects are performed in multi-project environments (Payne 1995). Nevertheless, only those aspects considered to be most urgent have been covered. Thus, the efforts invested in developing PPM guidance have been mainly focused on the project selection and prioritization, even if broader approaches have been documented (Pennypacker and Dye 2002). Indeed, in these contexts resources are limited and their capacity is shared by existing projects, making the selection and prioritization of projects crucial (Dinsmore and Cooke-Davies 2006).

On the other hand, these works have been developed assuming certain stability and predictability levels which cannot always be taken for granted, especially when the contexts are uncertain or dynamic (Petit and Hobbs 2012). According to the authors, *Organizations facing higher uncertainty in dynamic environments put in place different approaches to maintain efficiency while keeping the organization flexible*. Indeed, changes of goals or priorities, short-term execution management needs, new projects and sudden opportunities are only a few examples of situations these contexts are plagued by. This leads to the conclusion that the solutions to properly manage these environments require something else than what is offered by those approaches.

Similarly, assuming that programs and projects are operational activities performed in organizations, Maylor et al. (2015) identify a gap in the literature regarding the competitive increase in project-based operations (PBOs). In this recent work they state that *Superior project delivery capability is the opportunity that has likewise been neglected by so many organizations. The cost of neglect is becoming increasingly clear and it will take time to (re)build excellence*. As they explain, in these environments there are problems that go beyond the Operations Management. On one hand, local improvements are not enough to gain the desired competitive advantage, and on the other hand it is not possible to be good at everything. As a consequence, priorities must be selected and trade-offs made, such as quality, delivery speed, price, etc. Thus, they conclude that even proper prioritization and selection, consistent with the strategy, won't be effective unless they are properly implemented, that is to say, until the consequent actions are defined and deployed to the resource level. This is consistent with Petit and Hobbs, who claim that *it is no longer sufficient to develop unique resources or capabilities (as initially proposed in the Resource-Based View) to gain a strategic advantage but that resources and capabilities must be constantly reallocated and reoptimized to*

adapt to changing environments. As a result, Maylor et al. (2015) provide a view of the PBO comprised of four elements: strategic intent, focus, fit and configuration of resources, concluding as well that the alignment is an important factor as it could be beneficial to achieving the global goals.

The recent work of Smith and Smith (2014) offers a different approach although it shares some aspects with the paper of Maylor et al. (2015). Instead of superior project delivery capability, the term *high due-date performance* is used, where Flow is the key to return on investment (ROI). They claim that the inability of companies to get and use the information needed to perform in alignment with the ROI is the main problem for many companies today. In other words, the way companies measure their performance, assuming that local efficiency improvements will lead to an improvement of the company's global efficiency, is causing the organizations to lose the connection to Flow.

In other works, the relevance of performance measurement and metrics was highlighted (Smith 2000; Smith and Smith 2014), which under this perspective become essential. Thus, these aspects influence behaviours, as people will act depending on how they will be assessed. Therefore, assessment and reward systems should be aligned with strategies and goals, avoiding invalid or misaligned measures and metrics. Some other authors agree with these statements, emphasizing the relevance of performance measurement (Melnyk et al. 2014). They identify some related problems, such as *the lack of fit between the environment, strategy and what is being measured*. Thus, the alignment seems to be a key ingredient for the proper management of the system yet again.

In summary, the perspectives provided by these and other authors suggest that there are many aspects requiring further research, especially considering the mutual influence they can exert over other factors.

The authors base this research on the opportunity provided by a real-world project. In order to enhance the comprehension, this document is arranged as follows: firstly, the main features of the observed company and its context are explained in Sect. 2. Secondly, the objectives of the research are deployed in Sect. 3. Thirdly, the details of the case study are explained in Sect. 4. Section 5 gathers the results of the research. Finally, the conclusions and further research areas are developed in Sect. 6.

2 The Background of the Company

This inquiry deals with the case of a company that offers integral solutions to other companies which develop new products. In particular, it is focused on the pre-launch stage. By integrating all the different phases involved (i.e. designing, engineering, prototyping and manufacturing) the company is capable of taking over the whole new product development process.

The company is arranged into two business units: *Prototypes and Manufacture of Products*, and *Checking Fixtures*. This research is limited to the latter, devoted to the manufacturing of checking fixtures for plastic pieces and stamping pieces. The Management identified the main problematic features as following:

- Highly customized products.
- Each product is linked to a project. Average duration between 6 and 8 working weeks.
- Lead time strongly influenced by the customer's involvement (1 intermediate milestone: acceptance of the design proposed by the company).
- Average portfolio consists of 80 projects, carrying out up to 50 of them simultaneously.
- 22 workers involved in this business unit.

From the customer's perspective, the service is considered to be good. Nevertheless, on-time deliveries are attained at the expense of huge efforts like frequent insertion of non-programmed tasks or considerable overtime.

In short, the company's sensation was that lack of knowledge and maturity in PM was the cause for an unsatisfactory performance considering capacity. Therefore, the company aimed at improving the existing PM system.

3 Objectives

As explained in the introduction above, case studies are very important sources for PM research as they provide experience and information suitable for this purpose. The basis for this paper is a practice-based research which aim goes beyond the analysis of the implementation project of a method in a specific company. The project itself has an intrinsic value for this purpose, as *there are very few descriptions of how firms can implement and maintain dynamic capabilities in practice* (Petit and Hobbs 2012). Nevertheless, this is not the focus of this research. Instead, it addresses a closer view of the problems related to a real-world context when facing a project that aims to change the behavior of the company through the alteration of rules, roles and habits. The attainment of an aligned management of the whole system entails that a framework capable of performing under real conditions must be available. In this case it required to direct the organization effectively, consistently and sustainably.

The achievement of the research objectives depends on the implementation project. It is important to highlight that the scope of this inquiry is limited to the first stage and that the vehicle for this research was the implementation process itself. Therefore, the results will be divided into two parts: results of the implementation project and results of the research. To ensure a better understanding, firstly the objective of the project is explained, followed by the objective of the research.

3.1 Objectives of the Implementation Project

As explained in Sect. 2, the company aimed at improving the existing PM system, so as to lead the company to better results in terms of service, management capability and profit. In order to fulfill this purpose a preliminary diagnosis was carried out as explained in Sect. 3.2. Said diagnosis provided a lot of valuable information to understand the system's features and problems, and led to the conclusion that the impressions of the interviewees were well-founded. As a result, it was decided to carry out a project to implement the Critical Chain Project Management (CCPM) method in the company as the most suitable solution. Furthermore, some specific objectives were stated for the project, even more demanding than those initially defined by the company. These objectives should be progressively reached, and therefore they were distributed into two consecutive stages, as explained below:

Stage 1 (implementation of CCPM):

The purpose of this phase was the design and effective implementation of those procedures needed to manage the projects according to the CCPM method (Goldratt 1997), specifically:

- Common management method and terminology for those people involved in projects.
- Definition of roles and responsibilities according to the method.
- Project launching synchronization mechanism.
- Precise visibility of the situation of projects and resources.

Stage 2 (continuous improvement):

The aim of this stage was to achieve measurable results by the progressive improvement of the system's performance based on the new status provided by the first stage. This phase is not included in the research.

3.2 Objectives of the Research

Right from the beginning of the implementation project the researchers identified a number of critical aspects. The relevance of these points was founded both on their individual potential influence and on the possible consequences of their combination. However, these aspects were not perceived by the company as being important. Furthermore, when facing these problems, the company tended to find individual solutions that would ideally solve these problems one by one, ignoring that they could affect or interfere with each other.

Considering the above, and in particular the existing gap between both internal (company) and external (researchers) perspectives, the objective of this inquiry is to get an insight into the question: *how do metrics, performance measurement and*

holistic management influence the due-date performance capabilities of a project-based company? The rationale for the design, the contents and the arrangement of the research are explained in Sect. 3.

4 Research Method and Case Study

Once the objectives of the research have been explained and the company and its context have been introduced, the research method used to conduct this inquiry is described in Sect. 4.1. Then, the case study is explained in Sect. 4.2.

4.1 Research Method

The starting point for the design of the research is the process suggested by Robson (2002). Accordingly, a research methodology must include both a research strategy and research tactics, covering the following aspects:

- Research strategy: identification of the research purpose; selection of the research strategy as well as the unit of analysis.
- Research tactics: data collection methods and analysis of data and evaluation

There are three possible purposes for a research: exploratory, descriptive and explanatory (Robson 2002). When the purpose is exploratory, the aim is to understand how a new phenomenon takes place, identifying key issues and variables. If the study explores and explains a topic providing additional information, then the purpose is considered to be descriptive. Finally, the explanatory research purpose aims to understand why an event takes place, by analyzing the cause and effect relationship between variables. Taking the objective of the research into account, the explanatory purpose was discarded, and only the exploratory and the descriptive purposes remained valid.

According to Robson (2002), depending on its features a research can be qualitative or quantitative. A research is considered to be qualitative when it is based on non-numerical information, oriented to discover or refine research questions. Quantitative research is based on mathematical or numerical data, statistical or computational techniques to determine patterns of behavior or test theories, which are not the aim of this research.

Due to the special features of management research (MR), another kind of research different from the traditional approaches may be more suitable (Easterby-Smith et al. 2002). Indeed, MR is characterized by singularities such as the need to consider the physical and the human elements of the organization at the same time (Drejer et al. 2000). In these contexts, the performing activities don't allow to take control of the events, forcing the researcher to study the phenomenon

according to the current situation. For instance, Case Studies (CS) can provide a depth that can't be achieved by other research methods (Rowley 2002; Wacker 1998). In this way, the access to information is direct, avoiding the limitations of other methods.

Under these conditions, CS-s may be the only possibility to research (McCutcheon and Meredith 1993). According to Yin (2009) CS *Investigate a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident*. He also states that case studies are useful when how and why questions are being asked about a contemporary set of events over which there is little or no control. Furthermore, case studies can also help to explain the complexities of real-life situations which may not be captured through experimental or survey research (Guide Jr and Srivastava 2000; De Massis and Kotlar 2014).

On the other hand, case study research may be conducted by Action Research (AR) (Meredith et al. 1989), a participative variant of case studies concurrent with the action (Coughlan and Coghlan 2002) where the researcher is a participant in the action (Easterby-Smith et al. 2002; Gummesson 2000), and tests a specific approach (Benbasat et al. 1987). It may be especially helpful to overcome limitations of traditional research when facing organizations' real-world problems, for process understanding (Platts and Gregory 1990) and on the management of capacity, flow and bottlenecks (Coughlan and Coghlan 2002).

Qualitative research aims at a deep understanding and it rests on collecting, analyzing, and interpreting data by observing what people do and say (Yin 2009). There are different ways to collect the data in a qualitative research. As the research was to be performed by the AR approach by participating in the implementation, many sources of information were available, providing access to lots of people and data as shown in Table 1. That approach allows the observation of the same phenomenon from different perspectives (Stake 2005; Yin 2009; De Massis and Kotlar 2014); and makes for convincing and accurate findings (Tracy 2010). Furthermore, triangulation can be applied, thus enhancing data credibility (De Massis and Kotlar 2014).

Table 1 Data sources used and strengths

Source of evidences	Strengths
Documentation	Letters, e-mail correspondence, administrative documents, …
Archival (sic) records	Helpful to verify the correct spelling and title names of organizations to be analyzed
Interviews	Can provide other specific details to corroborate information from other sources
Direct observation	One can create inferences, but it is important to treat them as clues worthy of further research
Participant-observation	Computer files and records such as service records, organizational records, maps, survey data, …

Adapted from Yin (2009)

Concluding, this research can be defined as a qualitative inquiry with exploratory and descriptive purposes, based on a holistic single case study and performed through participative action research, implying that the researcher takes an observer-participant role.

4.2 Case Study

In Sect. 3, the initial situation of the company was described, which aimed to improve the management of projects. In order to acquire a thorough knowledge of the context and the functioning of the organization, a series of preliminary actions, were conducted, such as meetings, interviews, observations, observation of management meetings as observers, or analysis of documents and information among others. The result was a preliminary needs assessment which led to two actions: a training course designed to enhance the PM capabilities of the staff involved, and a project for implementing the CCPM method in the business unit.

Having set the conditions for the implementation, the development of the two-stage implementation plan was addressed, as mentioned in Sect. 3. However, the implementation progressed in a different way, influenced by the wishes of the company. Thus, phase 1 was interrupted before completion to incorporate some major changes. As detailed in Sect. 3.2, certain aspects that according to the researchers' perspective didn't fit the characteristics of the company's context were identified in the diagnosis. Some examples were the way projects were planned; as well as the organization and management of the resources. However, despite the insistence of researchers, the management initially refused to make any modification to the existing arrangement of resources, characterized by a segmentation of the resources into two semi-independent teams.

Thus, the first stage aimed to design and effectively implement those procedures required to manage the projects according to the CCPM method. For this purpose the following set of actions was proposed: review of the project modeling and management approaches; analysis of the organizational structure; definition and implementation of the management processes; and adaptation and implementation of the software. These activities were simultaneously performed, in coordination with training activities. It is noteworthy that the implementation activity developed in the organization led to meaningful changes and results within weeks from the beginning of the project; the most significant aspects being.

Access to updated and relevant information within the system

Despite the organization's experience in real-world PM, it lacked the means and know-how to enhance the existing PM approach by its own means. Consequently, development in this area was limited. Apart from its experience, its main assets in terms of management were a customized spreadsheet and its rigor to daily update it. As a result updated information was available, but the process was very time-consuming and the management information provided by the system was limited to a short-term load versus capacity perspective.

In response to this problem, software compatible with CCPM was implemented. Its ability to manage projects and resources in an integrated manner brought a lot of advantages beyond accessibility or usability of information. It became a key factor to achieving the *visibility*, in other words, information regarding issues such as the progress status of projects versus deadline, resources' expected load versus capacity ratio or prioritized task lists for resources, among others.

Impact of the customer's acceptance

Customer requests were addressed as a single project from start to finish. The project started with a design stage. Ideally, the design and the corresponding deadlines would be accepted by the customer by an agreed point in time. Then, the manufacturing phase would be launched.

However, reality proved to be different. Very often, the customer failed to give an answer by the agreed milestone, thereby generating delays that negatively impacted on the project plan; as well as on resource availability, and the company's cash flow.

It was noted also that those projects affected by this problem tended to suffer significantly more. Further analysis revealed that this was not only due to external factors such as customers' behavior, but to the capabilities and attitudes of the individual project managers. In particular, it was found that those project managers working proactively towards achieving customer acceptance managed to get results within the agreed period much more frequently; in contrast to the results of those who just waited for the customer to react.

The solution to this problem was posed by a different planning approach: the customer's request would be modeled as a project comprised of two subprojects, namely Design and Manufacturing. The launch of the second project would be conditional upon the acceptance of the design by the customer by an agreed deadline. Thus, both the individual management of each project and the multi-project management would be easily managed in accordance with the current circumstances. It was also decided to keep track of the on-time acceptance rates of the designs, thus urging project managers to perform more proactively.

Management limitations caused by the segmentation of resources

The reason for the segmentation of resources was to make better use of their capabilities. By means of dividing the workforce into two teams, their management was expected to become simpler. Projects were straight away assigned to one of the teams, which would handle the project until its completion. The monitoring showed, however, that this approach was inappropriate in a context characterized by uncertainty and dynamism, and constantly changing situations. Figure 1 depicts the situation at any given time in the project: the prevailing variability in the system led to load versus capacity imbalances on both teams at different times. Since each team was responsible for managing their projects, the solutions proposed were limited to their respective individual domains.

However, the management of all projects and all resources as a whole would have led to a less complex situation, requiring an easier and more reliable solution. Starting off with the implementation in a two-team scenario as insisted upon by the

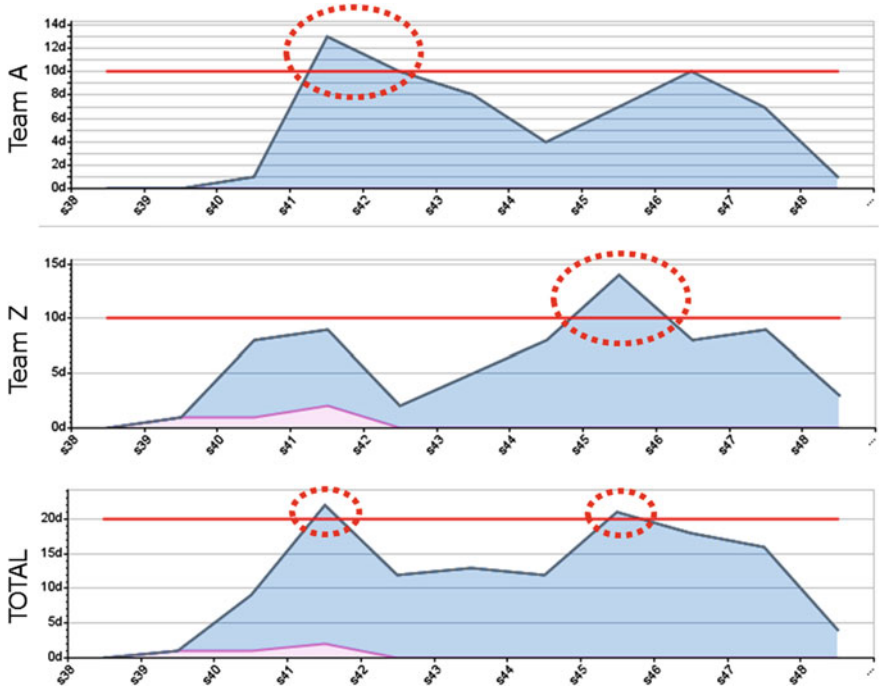


Fig. 1 Expected workload in Team 1, Team 2 and total (Team 1 + Team 2)

management caused the implementation process to be interrupted. The management eventually agreed to moving on to a single-team scenario as had originally been suggested by the researchers. The management concluded that the application of the new method had led them to gaining new insights. By combining the original two teams into one unit, the former policies that had been blocking the alignment of resources were removed. This decision led to several changes oriented towards enhancing the alignment, such as the creation of some new roles, the changes of the responsibilities of other roles, and the adaptation of both the software and the teams' management to the new situation, among others.

Impact of the local measurements on the global result

Despite the prioritization introduced into the system, namely to have clearly defined objectives and to have received specific training, there were still problems to work as intended. The workload imbalances as discussed above were a clear example of this, leading to situations where some members of staff could temporarily be out of work. These situations tended to generate nervousness and conflicts, leading to an urgent reprogramming of the workload in order to accelerate other jobs. This in turn entailed additional and unforeseen administrative and management work, for the sole purpose of avoiding idle resources. Moreover, these changes in general caused major disruptions, affecting more resources and jeopardizing the due-date performance.

However, this was not the only sign of misalignment or disorientation, as other similar situations arose, e.g. the creation of larger batches of work to increase *productivity*, or the pressure to start working on projects as soon as possible. This in turn led staff members to allocating a part of their working day to several projects simultaneously, which consequently resulted in a negative impact on the delivery date of the projects. The underlying problem in these situations was a local misalignment with the global objectives, mainly caused by the inconsistency of objectives and local metrics. Other factors were inertia and resistance to change. The way to overcome this misalignment was to give guidance to the staff in their daily activities and in the weekly review meetings, monitoring problems and results.

5 Results of the Implementation Project—Phase 1

The result of the first stage of the Project was the effective implementation of the CCPM method in the company. Thereby the main objective stated in Sect. 3.1 was met: *design and effective implementation of those procedures needed to manage the projects according to the CCPM method*. In fact, the company has performed autonomously and in line with the method since stage 1 had been completed.

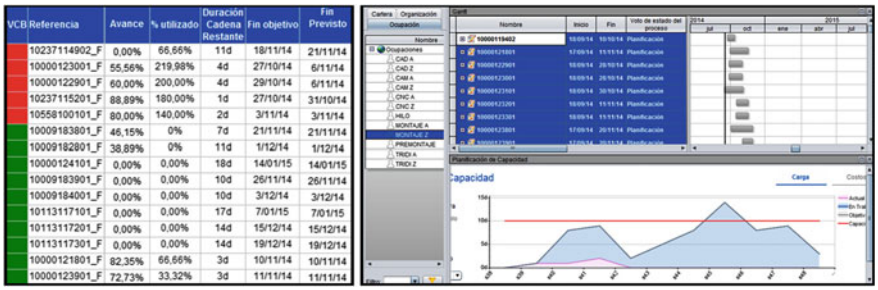
Furthermore, the remaining objectives related to this phase as explained in Sect. 3.1 were also reached. Certain other factors were crucial as they influenced both the result of the implementation and the managing capability acquired by the system. Those aspects are:

Achievement of global and local visibility:

The new system provided a clear, accurate view of the progress of projects and tasks, as well as the resources. Consequently, each employee had access to relevant information. This dynamism of the information resulted in more, speedier and better decisions, as deviations were identified faster, and decisions were based on updated information. The previous information system, although it had also been updated daily, was not capable of providing such complete information, in particular regarding the relative priorities of tasks and projects according to their current situation, as depicted in Figs. 1 and 2.

Reduction of the impact caused by the company's customers:

A two-stage approach for project planning was implemented in order to limit external impact. As a result, the PM was improved, indirectly also improving the allocation of resources. By dividing the project into two parts, management of the system became faster and more flexible as consequent adjustments were progressively introduced. For instance, the excess of unnecessary information in the system while waiting for customers' acceptance of the first stage was dramatically reduced. In fact, even before launching the second stage, problems such as the preventive resource allocation for activities without confirmed dates were reduced. The number



VCB	Referencia	Avance	% utilizado	Duración Cadena Restante	Fin objetivo	Fin Previsto
	10237114902_F	0,00%	66,66%	11d	18/11/14	21/11/14
	10000123001_F	55,56%	219,98%	4d	27/10/14	6/11/14
	10000122901_F	60,00%	200,00%	4d	29/10/14	6/11/14
	10237115201_F	88,89%	180,00%	1d	27/10/14	31/10/14
	10558100101_F	80,00%	140,00%	2d	3/11/14	3/11/14
	10009183801_F	46,15%	0%	7d	21/11/14	21/11/14
	10009182801_F	38,89%	0%	11d	1/12/14	1/12/14
	10000124101_F	0,00%	0,00%	18d	14/01/15	14/01/15
	10009183901_F	0,00%	0,00%	10d	26/11/14	26/11/14
	10009184001_F	0,00%	0,00%	10d	3/12/14	3/12/14
	10113117101_F	0,00%	0,00%	17d	7/01/15	7/01/15
	10113117201_F	0,00%	0,00%	14d	15/12/14	15/12/14
	10113117301_F	0,00%	0,00%	14d	19/12/14	19/12/14
	10000121801_F	82,35%	66,66%	3d	10/11/14	10/11/14
	10000123901_F	72,73%	33,32%	3d	11/11/14	11/11/14

Fig. 2 Examples of information about the current state of the system: projects (*left* deadline vs. projected end date today) and resources (*right* load vs. capacity for resource *Montaje Z*)

of projects potentially requiring the same resource in the same week was reduced by more than 50%, and resource requests were based on real needs according to deadlines and priorities. This in turn led to a reduction of both the artificially created uncertainty and the consequent efforts demanded from the staff caused by said uncertainty, enabling the system to give a faster and more effective response to the real needs at every moment.

Aligned management of the system:

The alignment of the company as a whole towards common objectives is considered to be the fundamental achievement of phase 1. The trend observed in the immediate period following this stage shows the impact of this fact clearly: dynamic reduction of overtime as well as the improvement of the time-estimates to complete upcoming tasks. Even though it is still early to accurately quantify results, in the short time of observation since phase 1 was completed, reduction of task duration is estimated to be about 20% on average, peaking at reductions of up to 50%. These results are even more relevant considering that the workforce was the same as prior to the implementation of the project.

The implementation of the CCPM method enabled the staff to perform consistently towards the global objectives and priorities of the company. The holistic nature of the CCPM method made this endeavor easier. Thus, operational tasks such as prioritization and resource assignment could be carried out according to the progress of projects, the availability of resources, and the relative urgency of activities.

Finally, the results exceeded the objectives set for stage 1. One example is the manifestation of the aggressive duration estimates used by the method during implementation even in routine jobs, and using the same resources. This demonstrates that as a result of the changes productivity, and therefore capacity, were being increased. Nevertheless, the overall system will benefit from this change only by turning the local improvement into a global improvement, enhancing the global results, which were aimed at in stage 2.

6 Findings, Conclusions and Future Research

This research is focused on the organizational aspects of a project-based company performing in a multi-project environment. The outcome of stage 1 of the implementation project was better management and control of the system, in other words, consistency between objectives and achievements. The key was the consistent alignment of local decisions and actions with the global objectives at any given time, based on the combined outcomes as explained in Sect. 5. Enhancement of PM know-how and skills were essential. Software as key to information availability (i.e., visibility) on one hand; and the management team's direct involvement in the implementation of the decisions on the other hand, were crucial factors to the successful conclusion of the implementation.

The results and findings confirm the influence of metrics, performance measurement and holistic management on the due-date performance of a company. This is consistent with the theories outlined in the introduction. It is proven that the entire system must be aligned with the strategy in order to achieve the desired results. This has several implications: firstly, it involves all levels of the company to be oriented and aligned towards its goals, from the top management to the most basic operational level. Secondly, there must be a consistent framework driven by metrics and performance measurements. Thirdly, this framework must enable efficient and sustainable organizational alignment.

The research project came to further relevant conclusions regarding certain key factors and corresponding implications as explained below; including suggestions for future research:

- The CCPM method was crucial to achieving the desired results. Its holistic nature made the construction of the new context fast and easy, providing whatever means were needed to perform accordingly. Supported by appropriate software, the method acted as an eye-opener, enabling the staff to understand and take advantage of a wider range of skills. The present results and findings would probably not have been reached by using a non-holistic approach.
- The decision of segmenting the capacity of the whole system must be deeply and carefully analyzed in its own context before being definitively adopted. Otherwise, the organization may be oriented towards individual objectives, neglecting the company's overall goals and performing below the company's actual capacity. Structural decisions involving the segmentation and amended use of resources require a previous understanding of their impact on the global results, as well as the management of the whole system. More research is needed to identify these aspects and their potential impact on a system's performance.
- The way that projects are planned, it not only delimits the potential of the company, but may also constrain its performance. This conclusion is closely related to the way a company understands a project plan, and is especially meaningful if the use of a said plan is limited to a mere representation of the work to be done, overlooking other potentialities. As explained in Sects. 4.2 and 5, the development of strategies for the PM to consistently reconcile different factors is

key to performance. The suggested starting point is the simultaneous management of single projects and shared resources, covering both plans and their execution. Even though different theoretical approaches for this purpose already exist, the challenge is to find a way to appropriately deal with all kinds of upcoming issues.

- The definition of an appropriate system of metrics with a holistic perspective is a factor of special interest. This seems to be a key driver for companies, as the alignment of the system as a whole is crucial. In actual fact, the global result of a company is a consequence of locally taken actions and decisions. Therefore, in practice consistency is essential to achieving the alignment towards the global goal. The metrics, as the main influence on workers' behavior, are key to this end.

Finally, it must be highlighted that these suggested factors should be addressed in a consistent manner, by means of a global approach and not as a sum of individual responses to different problems. The holistic perspective serves as basis for the present results.

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

The Dilemma of Innovation in the Construction Company: A Decade of Lessons Learned

Eugenio Pellicer, Víctor Yepes, Christian Luis Correa and Luis Fernando Alarcón

Abstract Innovation can be defined as the integration of non-trivial ideas capable of generating positive changes that increase a company's competitiveness. For construction companies, innovation is not an easy task, since their production is based on single projects built in different locations. This article summarizes the exploratory research conducted by the authors over the last decade, focused on the implementation, development and monitoring of a standardized innovation management system in a mid-size Spanish construction company. Collected evidence, also contrasted with other companies as well as with the sector as a whole, provide lessons learned, not only for the analyzed company, but also for construction companies in general. Innovation, in this kind of businesses, may not be a spontaneous act that appears on solving a specific problem, becoming a managerial process that can be systematized and homogenized. It allows faster identification of the involved tasks in creating new processes, products and services for companies and, therefore, their market competitiveness is improved.

Keywords Construction company · Innovation · Management · Standardization · Systematization

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1 Introduction

Innovation is an open concept that can have different meanings. Many authors historically have contributed their own definition of innovation, depending essentially on the context or scope in which they undertake their activity. Nevertheless, to avoid confusion, in this study, innovation is defined as the application of new ideas for the organization, regardless of whether these ideas are focused on products, processes, services or organizational, administrative or commercial systems, capable of generating positive changes that increase a company's competitiveness (definition adapted from Gibbons et al. 1994). Innovation management, on the other hand, can be considered as the creation of suitable conditions in an organization to make technological, organizational or commercial changes in an environment of uncertainty (Tidd et al. 1997). Having defined these two basic concepts, the problem detected must now be posited, serving as a starting point for the research reflected in this article.

The innovative capacity of a country depends on several key factors including, in particular, public policies that facilitate the advancement of innovation, the existence of regulations and laws that guarantee intellectual property, and a continuous collaboration between research centers and companies and institutions (Gann 1997; Mitropoulos and Tatum 2000; Seaden and Manseau 2001). Consequently, applying the commitments made in 2000 by the European Union in Lisbon, the Spanish government implemented various initiatives in the first decade of the new millennium, which in chronological order are the following:

- Law 4/2004 of Modification of Tax Rates and Benefits (Government of Spain 2004), which invites companies that invest in innovation activities to take advantage of tax incentives.
- The Ingenio Program (www.ingenio2010.es) launched in 2005, which seeks to reduce the innovation gap with the other Western economies through investment in public and private innovation.
- Set of standards UNE 166000, published in 2006 by AENOR, the aim of which is to systematize innovation management (AENOR 2006a, b, c).
- Inclusion of incentives in tendering for government contracts (up to 25% of the final score) for companies who show the implementation of innovative activities, preferably based on the set of standards UNE 166000 (Pellicer et al. 2008).

It is for this reason that, as the situation stood in 2006, many construction companies discussed whether innovation could be managed like any another additional company system (similar to quality, the environment or safety), so that it could be systematized and evaluated externally by a certifying agency according to the set of standards UNE 166000, for example (Pellicer et al. 2008). This is the point of departure of the research synthesized in this article, which yields the following main research question: Can innovation be systematized in a construction company? From this main question two more specific research questions arise:

Is the systematization of innovation beneficial for a company? What barriers exist to systematizing innovation?

This article summarizes the research conducted by the authors over the last nine years (2006–2014) focused on the implementation, development, evolution and follow-up of a standardized innovation management system in a mid-size Spanish construction company. The findings, also contrasted with other similar companies as well as the sector, provide lessons learned, not just for the company analyzed, but also for construction companies in general.

The article is organized as follows: First, the authors' research method is described. Next, the innovation management processes, implemented in the pilot company according to UNE 166002 standard, are explained. The following section justifies the in-company innovation management model developed by the authors. Then, the main results of the in-company implementation are presented. In the following section the most significant lessons learned are summarized. Finally, the conclusions, limitations and ongoing work are presented.

2 Research Method

As previously mentioned, in 2006, large and mid-size Spanish construction companies understood the systematization of innovation (according to the set of standards UNE 166000) as an opportunity to increase their company's competitiveness (Correa et al. 2007; Pellicer et al. 2008). At that time only one Spanish construction company was certified by the UNE 166002 standard (Pellicer et al. 2008, 2012). This is why the authors launched an exploratory investigation using analytical induction in the form of a single case study (Pellicer et al. 2010, 2012), based on the following research question: Can innovation be systematized in a construction company?

To select the company to study, the construction sector was researched in terms of its structure, considering two variables that define the size, revenues and employees (European Commission 2004), as well as the number of branch offices. Sixty five mid-size construction companies belonging to the associations FECOVAL, ANCI and SEOPAN were examined (Pellicer et al. 2012). Three companies very close to the average were identified, and were invited to participate; one accepted and became the focus of the case study. This construction company has been active in building and civil engineering projects since the 1960s, with revenues of approximately 400 million euros in 2006 (Pellicer et al. 2010, 2012).

The unit of analysis was the construction company as a whole: the headquarters, branch offices and construction sites. An in-depth analysis was carried out for three years that made it possible to implement the different processes required by the UNE 166002 standard and to verify their fulfillment and evolution. During that time all the branch offices were visited at least once, as were the ongoing construction

projects (more than a hundred), essentially those where potential innovative ideas arose. During the first year the company was analyzed in-depth (Pellicer et al. 2010), as well as the implementation of the innovation system according to the UNE 166002 standard (Yepes et al. 2016). In the two following years the success factors, benefits of and barriers to innovation were identified (Pellicer et al. 2012). In the first quarter of the fourth year, the results (success factors, benefits and barriers) were contrasted with other companies that had also implemented their innovation management system according to UNE 166002 (Pellicer et al. 2014). From 2009, a follow-up was done of the evolution of the innovation management system as well as of the company itself (Pellicer et al. 2012; Yepes et al. 2016).

The case study conformed to the guidelines proposed by Yin (2003), including the following six steps (Pellicer et al. 2012): (a) literature review; (b) theoretical model design; (c) data collection; (d) data analysis; (e) results of the study; and (f) generalization of results. With the first five steps, a comparison was made between theory and reality using multiple sources of evidence and logically linking the facts in order to explain this scenario. To fulfill this objective, the following sources of information were used (Pellicer et al. 2012, 2014): (1) participant observation for short periods of time (normally days); (2) monthly meetings with company management; (3) analysis of documents issued by the company or related to it (including websites); (4) external survey applied to 148 Spanish construction companies regarding their perception of innovation in construction; (5) annual survey (in the first three years) of the company management; (6) survey administered to company employees (in the second year of the study); (7) survey of suppliers and subcontractors (also during the second year); and (8) workshops for management and clients held annual or biannually from the third year on.

To ensure the quality of the research using a single case study, the indications of Yin (2003) were followed: (a) use of multiple data sources (as mentioned previously) to triangulate the facts; (b) generation of chains of evidence; (c) contrast of the theory with the observed reality (or pattern matching); and (d) explanation of the phenomenon in a logical manner (or explanation building). The first two aspects ensured the construct validity of the case study, whereas the last two guaranteed the internal validity of the research (Pellicer et al. 2012).

The external validity was accomplished using semi-structured interviews with the management of seven Spanish construction companies (of the eight possible ones) that had an innovation management system certified by UNE 166002 at the beginning of 2009 (Pellicer et al. 2014). The heads of each one of the company's innovation department were interviewed, all of whom had more than 15 years of experience in the sector. Additionally, eight managers from the company under study were interviewed as well as nine experts from the construction sector not linked to contractors.

3 Innovation Management Processes Based on UNE 166002

UNE 166002:2006 "R&D&i management: requirements for R&D&i management systems" defines the innovation management system (AENOR 2006c). This system comprises the company's global management system that includes the organizational structure, planning, responsibilities, processes, procedures, records and resources. UNE 166002 defines the manner of developing, implementing, executing, reviewing and maintaining the company's innovation policy (AENOR 2006c). The innovation system is divided into five basic processes (Yepes et al. 2016): (a) technological watch (according to UNE 166006); (b) creativity; (c) planning and development of innovation projects (according to UNE 166001); (d) technology transfer; and (e) protection of results.

Next, the five basic processes that include the innovation management system implemented in the pilot company are described (Yepes et al. 2016):

- Technological watch is a constant and organized effort to observe, obtain, analyze, disseminate and recover accurate information pertinent to the business context. It endeavors to detect opportunities and threats, as well as to anticipate changes that minimize decision making. The process of technological monitoring is regulated by UNE 166006:2011 "R&D&i management: technological watch and competitive intelligence system" (AENOR 2011).
- Creativity is the generation of ideas on the part of the employees that can stem from the analysis of the weaknesses, threats, strengths and opportunities of innovation, or from issues that arise in the construction works. The ideas are stored in a database. These ideas are valued according to their technical and economic feasibility and their affinity with the strategic lines previously established by the company.
- The planning and development of the innovation project not only considers its detailed design, but also its implementation in the construction project. On many occasions, both aspects can be almost parallel when the cause is to solve a problem that has arisen on the site. Normally, the person in charge of the project is the construction site manager. A detailed report including the project planning is needed prior to implementation; then follow-up reports are necessary, finalizing the process with the preparation and delivery of a closing report. The process is regulated by UNE 166001:2006; "Management of R+D+i: Requirements of a R+D+i project" (AENOR 2006b); each project can be certified externally by an agency recognized by the Government of Spain (Pellicer et al. 2008).
- Technology transfer is the process of acquisition, transfer, exchange, granting of licenses and permissions, and positioning in the market. It is oriented toward securing a competitive advantage in the market from the outcomes of the innovation activities. It can end up with signing a contract. In any case, it is advisable to evaluate the technology transfer.

- The company also seeks to protect sensitive information through confidentiality clauses when new employees are hired or cooperation agreements are signed with other organizations. As in the previous case, it is also advisable to evaluate the protection of results.

This set of processes involves feedback from the system. It is therefore important to have indicators, as well as results of the previous implementations, even if they are partial results or recommendations by those in charge of the innovation projects or construction site managers (Yepes et al. 2016). These results can be stored in a database to which all members of the organization have access. They can include usual sources of information, technological monitoring records, ideas, certified projects, partners, etc.

4 Innovation Model in Construction Companies

The proposed innovation management model is based on the open systems theory (Bertalanffy 1968), which comprises a set of interrelated elements to achieve specific objectives. It begins with the proposal by Seaden and Manseau (2001) focused on the company as a knowledge system, interlinked with suppliers, clients, resources, and even competitors. The innovation management model developed (Pellicer et al. 2012, 2014) considers that construction companies obtain novel ideas (input) from the company itself (normally at organizational or commercial level), as well as from construction sites. These ideas are transformed into innovation projects (output). All this is developed in the construction industry where the company is active (environment). To design a suitable innovation strategy, the company's business environment and organizational abilities are taken into consideration. These are reflected in the goals and policies that facilitate communications within the organization. Consequently, the results of the innovation projects have an impact on the company and its construction projects.

The results of the study generated 18 propositions, which are shown in Fig. 1 (Pellicer et al. 2012, 2014) and detailed in Table 1 (Pellicer et al. 2012, 2014). These propositions are organized around the following aspects of the innovation management process (Correa et al. 2007; Pellicer et al. 2012): innovation drivers, results from innovation, innovation system, business environment, and organizational capabilities. Table 1 also includes the scientific contributions that support each of the propositions in the model.

These 18 propositions were subjected to validation as explained in the research method. The results of the validation revealed a broad consensus among the three groups interviewed, which confirmed 15 of the 18 formulated propositions beyond doubt. Three of the propositions were only weakly supported: P4, P15 and P16. The proposition with the least support states that when adopting an innovation management system in a construction company, innovation can be achieved using a

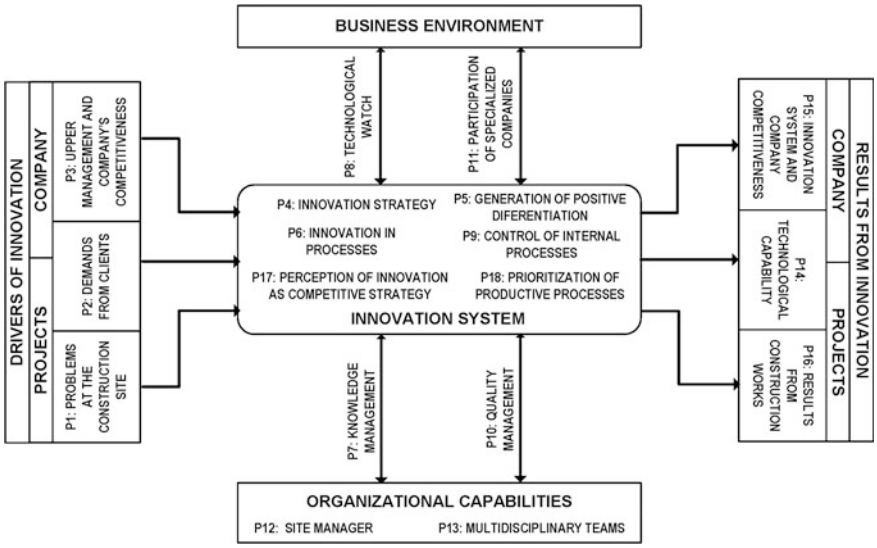

Fig. 1 Innovation management model and its propositions (Pellicer et al. 2012, 2014), with permission from ASEM and ASCE respectively

previously defined strategy. It is possible that, when innovation management is not sufficiently mature, informal strategies do not allow perceiving the advantages of innovation.

5 Results of the Implementation

Once the main phase of the research had been carried out (2006–2009), which included the implementation of the processes and formulation of the propositions that define the innovation management model, a follow-up was done of the company's performance. Table 2 shows the company's evolution during the nine years of observation (from 2006 to 2014, although in this last year only partially). The data include revenues, profits before taxes, employees with university degrees and employees working in the innovation department, and innovation projects that have been certified by an external agency. The company implemented the innovation management system in 2007 and it was certified by AENOR (external agency) in 2008 (Pellicer et al. 2012). The data in Table 2 must be interpreted in the context of the crisis in the Spanish construction sector starting in 2008 (Torres-Machí et al. 2013; Oviedo-Haito et al. 2014). To facilitate comparison with the sector in general, the production indexes in building and civil engineering in Spain for that period are also included (SEOPAN 2014).

Table 1 Propositions and main references that support them (Pellicer et al. 2012, 2014)

Code	Proposition	References
P1	Innovation comes from technical problems that arise in project execution at the construction site	Slaughter (1993), Nam and Tatum (1997), Winch (1998)
P2	Construction companies innovate to meet client requirements	Nam and Tatum (1997), Mitropoulos and Tatum (2000), Blayse and Manley (2004)
P3	Senior management propels innovation projects to improve the competitiveness of the company	Tatum (1987), Winch (1998), Slaughter (2000)
P4	By adopting an innovation management system, innovation follows a previously defined strategy	Gann and Salter (2000), Seaden et al. (2003), Stewart and Fenn (2006)
P5	By implementing an innovation management system, the company responds to the need to generate positive differentiation that is valued by clients	Slaughter (2000), Sexton and Barrett (2003), Van den Ven and Poole (2005)
P6	Construction companies generally innovate in processes	Gann and Salter (2000), Sexton and Barrett (2003)
P7	The implementation of an innovation management system improves knowledge management	Winch (1998), Parikh (2001), Hardie et al. (2005)
P8	Construction companies that adopt an innovation management system understand their environment better	Tatum (1987), Pries and Janszen (1995), Seaden et al. (2003)
P9	The control of internal processes (mainly production and management) constitutes a basic source for generating innovative ideas	Dulaimi (1995), Stewart and Fenn (2006), Kornish and Ulrich (2011)
P10	The existence of a quality system certified by the ISO 9001 standard facilitates the implementation of an innovation management system	Prajodo and Sohal (2006), Santos-Vijande and Alvarez-Gonzalez (2007), Casadesus et al. (2011)
P11	The existence of an innovation management system stimulates subcontracting to specialized companies and adds value to the innovation process	Blayse and Manley (2004), Wagner (2006)
P12	The active involvement of the site manager in the innovation process has a significant impact on the results of innovation	Park et al. (2004), Dulaimi et al. (2005)
P13	Innovation in construction requires the participation of multidisciplinary teams	Gann and Salter (2000), Bossink (2004)
P14	The adoption of an innovation management system improves the company's technological capabilities	Tatum (1987), Nam and Tatum (1992), Slaughter (2000)
P15	The adoption of an innovation management system improves the company's competitiveness	Tatum (1987), Nam and Tatum (1992), Mitropoulus and Tatum (2000)
P16	The certification of an innovation project improves the results of construction projects	Marimon and Cristobal (2005), Vea et al. (2010)
P17	Innovation in construction is delayed when senior management does not perceive it as a competitive strategy	Nam and Tatum (1997), Slaughter (2000), Blayse and Manley (2004)
P18	The prioritization of production processes hinders the identification of innovation opportunities	Tatum (1986), Pries and Janszen (1995), Gann and Salter (2000)

Table 2 Evolution of the company and the Spanish construction industry for the period 2006–2014 (Yepes et al. 2016)

Indicators (data from 12/31/2014)	2006	2007	2008	2009	2010	2011	2012	2013	2014
Revenues (in millions of Euros)	451.3	488.1	567.6	591.2	475.6	396.8	279.9	238.6	NA
Profit before taxes (in millions of Euros)	6.7	8.2	15.4	17.9	12.2	3.1	−7.8	0.5	NA
Employees with university degree	37	42	53	56	48	45	40	38	39
Employees working at the innov. dept.	1	3	4	4	4	4	4	3	4
Annual innovation projects certified	0	1	1	6	11	9	8	5	11
Production index for building	183	174	146	121	100	81	78	80	NA
Production index for civil engineering	150	147	123	145	100	79	67	63	NA

Analyzing the data in Table 2, it is observed that company profits tripled from 2006 to 2009, while the revenues increased only a third and the construction sector remained stable, at least in civil engineering. In that period, there was a spectacular increase in certified projects, as well as in qualified personnel and technicians working in the innovation department. These results show the benefits of implementing an innovation management system in a mid-size company, at least from the point of view of the innovation projects; obviously, this does not necessarily mean that there is a direct relation between profits and innovation, this being a question for future research.

For 2010–2014, company revenues and profits decreased, just as it did in the Spanish construction industry as a whole. However, the innovation department stayed stable for three years (2010–2012) despite the crisis, maintaining the same personnel and with an acceptable production in innovation projects.

Additionally, the company's innovation department garnered great prestige among company employees, given that even in times of crisis it worked at a good pace. For example, some innovation projects increased productivity, such as optimization of manufacturing, transportation and application of asphalt mixtures, or the improvement in the process of shoring and removal of formwork in underground parking lots. Other projects improved the flow of information: between the offices and construction sites using mobile devices, with suppliers and subcontractors through a computerized system, or with workers on site using an intelligent planning and control procedure. For these reasons, the directors and managers of the company sensed that, over time, clients, suppliers and subcontractors came to see the company as an innovator. For company management, implementation of the innovation management system was a success.

6 Lessons Learned

The systematization of innovation helps to assimilate new ideas and, therefore, to disseminate new knowledge in the company. Initially, the main sources of creativity in the construction company were solving problems at construction sites and meeting client demands, always with the support of company management. Once the system was implemented, however, the following processes were followed: technology watch, creativity, project planning and development, technology transfer and protection of results. In any case, problem solving continues to be the main innovation source, fulfilling several objectives: (1) those inherent to each construction site; (2) improvement of the productive processes that can be replicated on future projects; and (3) increased scoring (in the innovation section) for upcoming public tenders.

During the nine years of this investigation, the lessons learned regarding the implementation, development and evolution of the systematic management of innovation in construction companies have been many, especially the following:

- The establishment of an innovation management system modifies the company's organizational structure, even if this is only by the creation of a specific innovation department.
- The previous existence of a quality management system facilitates and benefits the implementation of an innovation management system.
- The construction company mainly innovates through processes and their related products.
- Innovation opportunities are identified as a result of the evaluation of the company's internal processes, as well as construction projects and the environment.
- The identification, development and transfer of innovative solutions require the integration of several disciplines: (1) observation of the environment, including technological watch, to identify opportunities to innovate, feasible solutions and technology partners who add value to the innovation process; (2) knowledge management in the organization so that findings are transferred to other projects, either innovation or production projects; and (3) the ability to discern the specific demands of clients.
- Collaboration with technology partners and the management of multidisciplinary equipment are necessary conditions to generate innovation in construction companies.
- The main benefit of innovation management is an increase in technical capacity.
- The two main barriers to innovation are the prioritization of production over everything else and the underestimation of innovation as a competitive strategy on the part of the company's senior management.
- Standardizing innovation different benefits are obtained for the company: improvement of the organization, increased technical capacities, profit, and client satisfaction.

- The implementation of an innovation management system is an opportunity to implement a knowledge management system in the company (Pellicer et al. 2008; Yepes et al. 2016).

7 Conclusions

This article presents the implementation, development and evolution of an innovation management system in construction companies. It is based on the case study of a mid-size construction company, the results of which were contrasted through interviews with other companies also certified by the UNE 166002 standard. Moreover, the study also includes an analysis of the evolution of the company once the system has been implemented.

Most companies generate innovative products and processes; however, the main difficulty lies in carrying out continuous and methodical innovation, far from occasional efforts and happy ideas. Innovation must be planned, organized, directed and controlled, like any other business activity.

Innovation in companies in the construction sector may cease to be a spontaneous act that only arises when solving a specific problem, and become a systematized and homogenized management process. The standardization of innovation, therefore, makes it possible to accelerate the identification of the activities involved in the creation of new processes, products and services in companies in the industry, and thus to improve their competitiveness in the market. The systematization of innovation not only facilitates the incorporation of new ideas, but also increases the capacity to acquire, develop and use new knowledge.

The main limitation of the present investigation is the generalization of the results obtained. This model cannot yet be generalized, despite contrasting the results of the implementation using semi-structured interviews with managers responsible for innovation in other certified companies. To this end, a validation could be carried out, for example, by means of a survey administered to a sufficient number of companies with an adequate degree of maturity in the systematic management of innovation. The implementation in other countries is another line of enquiry initiated by the authors; they aim to conduct case studies in countries like Chile, Portugal or Mexico.

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Part III
Product and Process Engineering and Industrial Design

Study on the Influence of Fresh White Cheese Packaging Design Variables on Users' Perception

Ignacio Gil, Rubén Rebollar, Iván Lidón and Javier Martín

Abstract Packaging design is a decisive factor in the perception that users have of a product before its consumption, so it is key to know precisely which design is the most suitable for the message that brands wish to convey. This research aims to study the influence of two variables, serving suggestion and label colour, on users' perception of products which, by themselves, do not have high aesthetic or taste appeal. The case of fresh white cheese was studied due to its high consumption in Spain and because it is usually accompanied by other products during consumption. Two hundred and forty seven people took part in a survey in which sensory attributes and the willingness to buy were analysed through the presentation of 8 different packaging proposals which designs were the result of the combination of 5 types of serving suggestions and 4 label colours. The results show that the serving suggestion is strongly related to both the users' sensory expectations and the appropriate time of day for consumption, and that the colour of the label influences the perceived fresh white cheese category.

Keywords Serving suggestion · Packaging · Perception · Label · Fresh white cheese

1 Introduction

Outer appearance of food packaging is a key element in attracting consumers' attention (Silayoi and Speece 2007) and stimulating purchase (Bloch 1995; Tuorila and Pangborn 1988). As much as 70% of all buying decisions are made in-store,

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even in those cases of planned shopping (Inman et al. 2013). Hence, packaging is not only used to hold and transport the product, but also for promoting it (Kauppinen-Räisänen 2014).

There is a wealth of scientific literature that shows the influence that several packaging cues such as shape (Rebollar et al. 2012; Becker et al. 2011), material (Mutsikiwa and Marumbwa 2013), or label (Charters et al. 1999; Orth et al. 2009) have on consumers. This study aims to shed light on how two of the main packaging cues, the product's image and packaging colour, influence consumers' perception and expectations.

Packages are often designed in a way that help the user get an accurate idea about what the product contained is really like. The use of transparent materials or product images is rather common. There is in fact good evidence that displaying a picture in the packaging has an impact on consumers. Liao et al. (2015) conducted an experiment in which consumer emotional response was measured when exposed to food packages labelled with images (product-related and non-related). Others have observed how the images displayed in the packaging influence consumers' willingness to buy (Bone and France 2001) or alter the sensory perception of the product (Mizutani et al. 2010).

To date, much emphasis has been placed on the emotional (Bone and France 2001; Liao et al. 2015; Mizutani et al. 2010) or communicative (Underwood et al. 2001; Underwood and Klein 2002; Miraballes et al. 2014) level of the image, considering it as a whole. However, an image can be divided into the different individual elements of which it is composed (e.g. other food products, pictures of people or props) and their influence on the consumer has never been isolated and studied.

Likewise, serving suggestions are a design tool widely used in food packaging in which the manufacturer displays the product ready for consumption, accompanied by other foods or props (usually dishes and/or cutlery), seeking to make the product more appetizing and/or informing consumers about how and when can it be consumed. Nevertheless, this has attracted little scientific attention to date. Therefore, this paper aims to fill this gap by studying the influence on the consumer expectations of the garnishes displayed in the serving suggestion.

Another major packaging design cue is colour. As in the case of the images displayed in the packaging, the background colour of the packaging has a strong impact on consumers, (Rebollar et al. 2012; Ares and Deliza 2010; Mohebbi 2014) so it is used as a priority marketing tool (Singh 2006; Labrecque and Milne 2012).

Colour has been studied in this context from several different angles. Commonly, research has been focused on the way colour influences consumer sensory expectations (Gollety and Guichard 2011; Kauppinen-Räisänen 2014), the consumer's experience (Becker et al. 2011; Smets and Overbeeke 1995) and even the consumer experiential expectations (Rebollar et al. 2012).

However, it is more difficult to find papers that analyse how consumers identify the category of the product based on its packaging colour. Some products (e.g. milk) use a colour code that allows the consumer to identify the intrinsic characteristics of the product (also distinguishing it from other similar products offered by the same brand). Despite being a communication tool widely used by brands, there is not any established chromatic code, so each brand choses the colour of their packages at its own discretion.

According to Grossman and Wisenblit (1999), consumers prefer some colours over others to identify a given product because they learn through association (their past experiences) that some colours are more suitable than others for some product categories. In the same line Piqueras-Fiszman et al. (2012) suggest that using the colour of a given food in its packaging will ease the association between package colour and product taste for the consumer.

However, there is a lack of studies that analyse how colour can be used to effectively identify products of the same family from the same brand. This research seeks to make advances in this area by analysing the case of a common product in Spain, fresh white cheese (*queso fresco*).

Fresh white cheese has been chosen for this study since, according to the Spanish Ministry of Agriculture, Food and Environment (MAGRAMA n.d.), this type of cheese has the highest consumption in Spanish households (29.9% of the total in 2013). Also, it is purchased mainly in supermarkets and hypermarkets, for this reason consumers are accustomed to purchasing this cheese as a packaged product.

From among all the categories of fresh white cheese on the Spanish market, this study focuses on those obtained from pasteurized milk (sheep, goat, or cow): a soft white cheese, cylindrical conical or prismatic, without crust and with a soft texture. It is very common for fresh white cheese packaging to show a serving suggestion with garnishes and a chromatic code for distinguishing between different product categories.

Henceforth this research has a double objective. Firstly, it aims to analyse the influence the foods used to garnish the cheese in the serving suggestion have on:

- Consumer expectations with respect to the attributes of the fresh white cheese,
- The time of day consumers believe most suitable for its consumption,
- Consumer willingness to buy.

Secondly, it aims to analyse the influence the colour of the packaging has on:

- The category of fresh white cheese the consumer thinks is contained inside the packaging,
- Consumer willingness to buy.

2 Materials and Methods

2.1 Participants

Some 247 people participated in this study during October and November 2014 (158 females). The mean age was 27.7 with a standard deviation of 10.4 years. With regard to consumption, 45% admitted consuming fresh white cheese from time to time, 24% on rare occasions, 21% frequently and the remaining 10% admitted never consuming fresh white cheese.

2.2 Procedure

The experiment was conducted online with an online survey provider, SurveyMonkey®. Participants were recruited on a voluntary basis on social media. The survey was responded to anonymously and without any time limit for its completion. During the course of the survey, participants were shown a series of photorealistic images in which the different fresh white cheese packages designed for this research were displayed. Each image was displayed with a questionnaire for its assessment. All survey participants saw the same packages shown in random order.

2.3 Stimuli

2.3.1 Serving Suggestion

This experiment was designed with five different packages in which the only variant was the garnishes used in the serving suggestion, which represented the foods most commonly consumed with fresh white cheese: two savoury alternatives (salad and sliced turkey), two sweet alternatives (fruit and quince cheese) and one package displaying just the fresh white cheese (without any garnish).

The fresh white cheese was the central item in the composition on each package with an identical position and size, with the garnish to the left. The other variables were identical. Care was taken to ensure that the relationship between the garnish and the fresh white cheese was consistent in all the packages. Hence, the packages were designed so that the space occupied by the garnish was similar on all of the packages. The five packages were designed over a blue background colour to prevent the interference between variables.

The five serving suggestion stimuli can be seen in Fig. 1.

Fig. 1 Visual stimuli used in the serving suggestion assessment

Fig. 2 Visual stimuli used in the packaging colour assessment

2.3.2 Packaging Colour

Four visual stimuli were designed to study the packaging colour, imitating the colours most commonly used in fresh white cheese packaging: blue, pink, green and white.

For these stimuli the only change is the background colour of the composition. The other variables were identical. The four packages were designed with a fruit garnish to prevent the interference between variables.

The four packaging colour stimuli can be seen in Fig. 2.

The eight visual stimuli were designed by imitating four-serving fresh white cheese packages. The packaging has a cardboard wrapping in which the textual and pictorial information is displayed. The wrapping was designed with regard to the position and the size of all the graphic elements displayed on commercial packages. The graphic elements displayed are the description of the product (the words fresh white cheese, *queso fresco* in Spanish), the brand (a fictitious one—*Torre blanca*, White tower—was created to prevent associations with real brands), the nutritional information and the product quantity (identical on all packages) and the serving suggestion.

The photorealistic mock-ups used as visual stimuli were created with the software Adobe Photoshop CS5 and Keyshot 4. The product pictures displayed on all of the packages were taken by the research team using natural products.

2.4 Measurements

The survey was divided into three sections: control questions to identify the participants (age, gender, and education), the presentation of the packages to be analysed and a survey related to the study variable.

Each participant assessed different factors for each of the eight packages, depending on whether it was a visual stimulus of the serving suggestion variable or it was a visual stimulus of the packaging colour variable. The list of the assessed cues for each assessment can be seen in Tables 1 and 2 respectively.

2.4.1 Serving Suggestion

Participants were asked to assess the four product attributes with a Likert-7 scale (1 being totally disagree and 7 being totally agree) and to pick the ideal time for consumption for each of the eight packaging alternatives. They were allowed to leave the questions blank if they wished to. A Likert-7 scale was also used to assess their willingness to buy (1 being I'd never buy it and 7 being I'd be perfectly willing to do so).

Participants were told that in each one of the eight packages the product quantity and the price were identical (although price was not revealed).

2.4.2 Packaging Colour

Participants were asked to pick which one of the four categories displayed they thought was contained in each package. Their willingness to buy was assessed as in the previous case using a Likert-7 scale (1 being I'd never buy it and 7 being I'd be perfectly willing to do so).

Table 1 Assessed cues for the serving suggestion variable

Product attributes	Time of consumption	Willingness
Sweet	Breakfast	Willingness to buy
Savoury	Lunch	
Healthy	Dinner	
Strong flavour	In-between meals	
	At any time	

Table 2 Assessed cues for the packaging colour variable

Fresh white cheese categories	Willingness
Natural	Willingness to buy
Low-cal	
Low salt	
No response	

As above, participants were told that in each one of the eight packages the product quantity and the price were identical (although price was not revealed).

2.5 Data Analysis

An ANOVA analysis of variance was used to analyse the data of the attributes and the willingness to buy. In doing so, each attribute was analysed individually and it was possible to know if there was a statistical difference between the means of the series of the results.

For the analysis of the data from the ideal time for consumption and the category of fresh white cheese that is believed to be associated with each package colour, a correspondence analysis was performed. By elaborating performing a contingency table, a Cartesian diagram was constructed. The Cartesian diagram was based on the association between the analysed variables analysed. The proximity between the plotted points is related to the level of association between the variables.

3 Results

3.1 Influence of the Serving Suggestion on Product Attributes Expectation

The four product attributes assessed in the serving suggestion study gave statistically significant values. Nonetheless, the results show that some garnishes have a stronger influence than others, the sharpest contrast being between *Sweet* and *Savoury*.

The ANOVA results can be seen in Fig. 3.

Regarding the *Sweet* attribute there is a marked difference between the garnishes of fruit and quince cheese and the others, quince cheese being the garnish which raises the sweetness expectation the most. The fresh white cheese without garnish is perceived as not very sweet, just above salad and sliced turkey.

In contrast, in the *Savoury* attribute a marked difference can be observed between the salad and the sliced turkey examples and the others, which are, contrary to above, the garnishes which raise higher expectations. The sliced turkey garnish shows the highest value and the quince cheese garnish the lowest.

Concerning the *Healthy* attribute, the five packaging alternatives get high values, with quince cheese obtaining the lowest value.

With the *Strong flavour* attribute, the salad and quince cheese garnishes elicit higher expectations, whereas the fresh white cheese without garnish is perceived as being the tasteless.

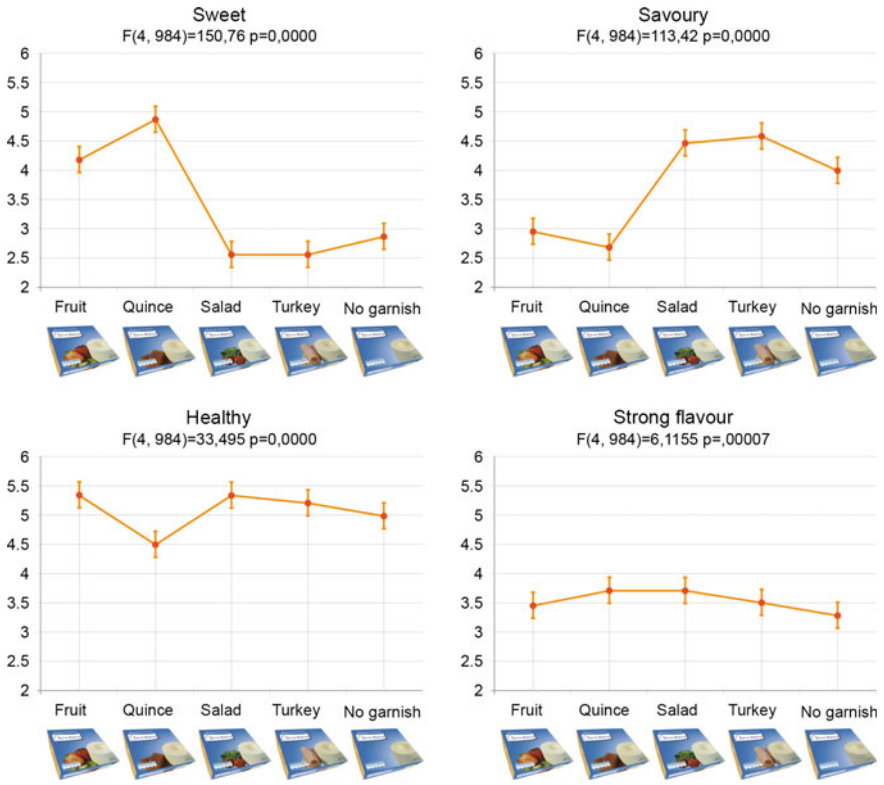

Fig. 3 ANOVA results of serving suggestion attributes

3.2 *Influence of Serving Suggestion on Time of Consumption*

A correspondence analysis that can be seen in Fig. 4 was conducted to analyse the influence of the serving suggestion on the time of consumption. The Chi-square association was significant (χ^2 = 345, *p*-value <0.0001).

The graph shows that the package displaying the salad garnish has a strong link with the consumption at *Lunch*, while the package where there is no garnish is clearly related to consumption *At any time*. However, it can also be seen how the other three package alternatives do not present a clear relationship with any particular time of consumption.

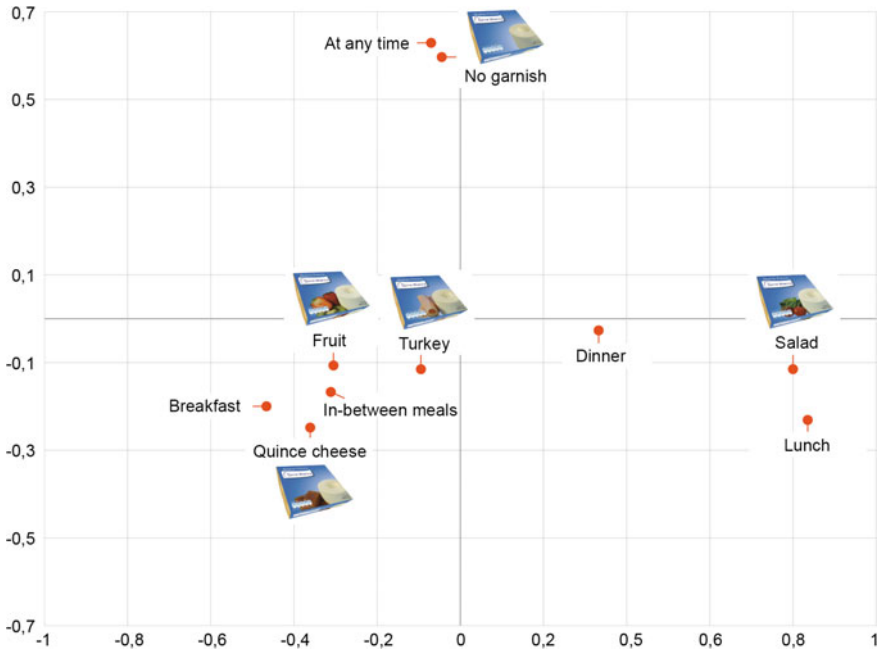

Fig. 4 Correspondence analysis for the serving suggestion variable

3.3 *Influence of Packaging Colour on Product Category Expectation*

A correspondence analysis that can be seen in Fig. 5 was conducted to analyse the influence of the packaging colour on product category expectation. The Chi-square association was significant (χ^2 = 103.36, *p*-value <0.0001).

The graph shows a link between the pink background and the *Low-cal* category of fresh white cheese. However, there are not clear relations between the other colours and the other fresh white cheese categories.

3.4 *Influence of the Serving Suggestion and the Packaging Colour on the Willingness to Buy*

The values obtained in the ANOVA analysis performed that can be seen in Fig. 6 gave statistically significant values. The blue packaging garnished with salad obtained the highest willingness to buy with a value of 4.54. On the other hand, the

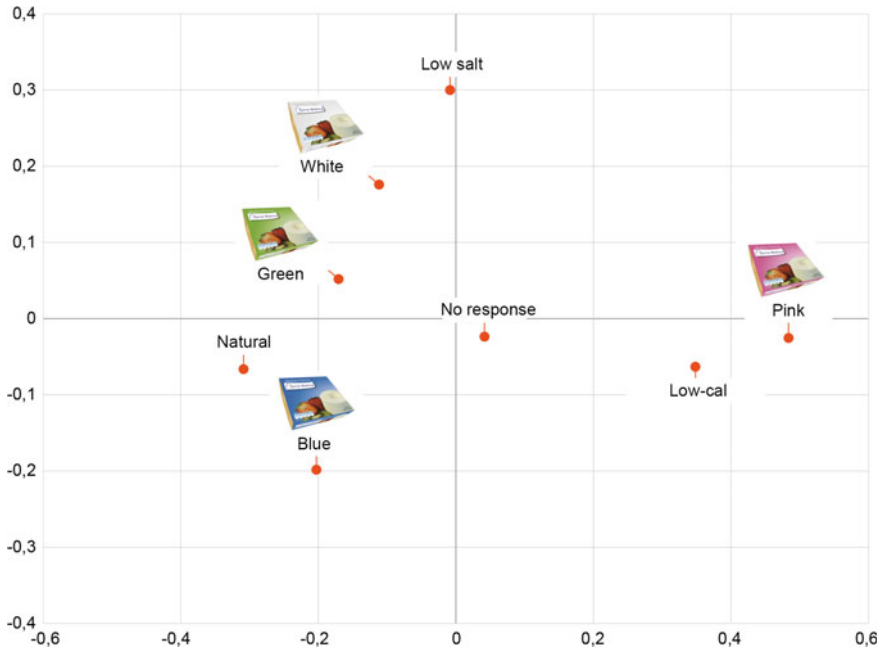

Fig. 5 Correspondence analysis for the packaging colour variable

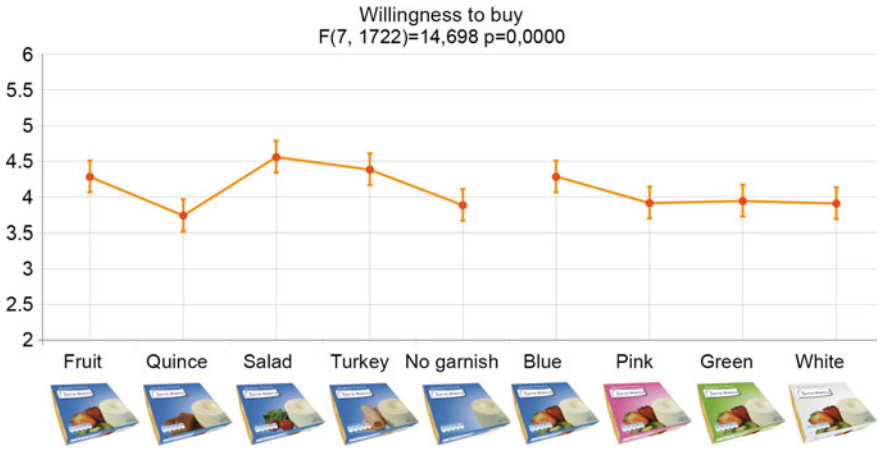

Fig. 6 Willingness to buy

lowest willingness to buy was elicited by the blue packaging garnished with quince cheese, with a value of 3.73.

In Fig. 6, the blue packaging garnished with fruit is displayed twice as a stimulus found in both experiments.

4 Discussion and Conclusion

The results show how the choice of the garnish displayed in the serving suggestion of fresh white cheese packages determines consumer expectations with respect to the attributes of the product.

The results show how consumers extrapolate the attributes of the garnishes on the cheese itself. Thus, one can see how the sweet garnishes (especially quince cheese, the sweetest of the garnishes) cause the cheese to be perceived as sweeter, and how the savoury garnishes raise the expectation that the cheese will be saltier.

The other attributes tested on the experiment, *Healthy* and *Strong flavour*, show more subtle differences depending on the serving suggestion displayed. In the case of the *Healthy* attribute, the packaging garnished with quince cheese stands out negatively, probably due to the association the consumer makes with a high-sugar and, thus, unhealthy diet. The consumer expects the fresh white cheese to be almost tasteless, so in the case of the attribute *Strong flavour* the values obtained are rather low. However, it is possible to see subtle differences depending on the serving suggestion displayed: the packages garnished with salad and with quince cheese are the ones with the higher values and unsurprisingly the ungarnished package has the lowest value.

The results also show that the serving suggestion influences the ideal time for consumption that is perceived by the consumer. Thus, the existent link between the salad garnish with the *Lunch* time and the strong link between the package without garnish and consumption *At any time* during the day are clearly visible. This provides robust results since the lack of a garnish means that no other information but that provided by the cheese itself is being sent to the consumer.

The negative bias on consumer expectation elicited by the sweeter garnishes is also visible in their willingness to buy. Regarding the serving suggestion, the package garnished with quince cheese and the package garnished with fruit (along with the package without garnish, probably due to the product's lack of attractiveness) are the serving suggestions with a lower willingness to buy.

The results also show the influence that the package colour has on both the identification of the fresh white cheese category and willingness to buy. With regard to the product category, a strong link between the pink package and the *Low-cal* category can be seen. Conversely, the blue package is the option with the highest willingness to buy. This is in all probability due to the pre-eminence of that colour in the fresh white cheese packaging market and the consequent consumer habituation to it.

The results obtained in this research therefore highlight how product communication and willingness to buy are affected by packaging design, which undoubtedly determines a product's chances for success on the market.

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Study, Design, Development and Construction of a Linear Tribometer for Testing Human Skin

Eurico Seabra, Luís F. Silva, José Martins and Mário Lima

Abstract The study of the tribological properties of the skin is a very important research field for medical investigation, development of dermatological products and the analysis of the interactions between textile products and the skin. To obtain these properties it is necessary to perform tests using tribological equipments which can simulate the conditions to obtain reliable values that will allow the measurement of skin wrinkling. The skin aggressions are usually analyzed using special equipments, known as tribometers, that enable the performance of the tribological characterization of a pair of materials, in order to obtain parameters such as friction coefficient and wear; for this purpose, the control of test variables, such as normal applied load, displacement speed, environmental conditions and other relevant circumstances which influence the interaction of surfaces in contact is required. The most important objective is the evaluation of a concept commonly known as touch, difficult to define and measure (which is related to the quantification of the level of comfort provided by the contact with the skin), with the requirement of studying soft materials, namely the skin. For that purpose it became necessary to design and manufacture a tribological equipment capable of responding to the demands of the required tests.

Keywords Mechanical design · Tribometer · Instrumentation and control · 3D modelling

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1 Introduction

The human skin is the largest organ of the human body, enabling a vital defense mechanism, by forming a barrier between the interior and the external environment. It not only contains but also supports and protects the internal organs of the body to a certain degree of abrasion, wear and bruising, also allowing a considerable mobility of the body (Elder et al. 2001).

The human skin is exposed to various types of attacks that can be mechanical, chemical or microbiological, promoting many problems to the skin. Many of these aggressions are caused by the interactions between the skin and textile products due to friction, by the application of creams and by the use of different medical devices, among others. These attacks tend to modify the properties of the skin, such as elasticity, roughness and moisture (Leonardi et al. 2002).

Therefore it is of upmost importance to study the skin interaction with other elements in order to minimize cases of skin damage, which often cause irritation and pain, or simply to improve comfort and quality of life. Tribometers are often used to analyze and better understand these phenomena. With this equipment it is possible to tribologically characterize the materials in contact and to obtain important parameters, such as coefficient of friction and wear. Therefore, the need to control the test variables (normal applied load, displacement speed, environmental conditions, lubrication, and others that are relevant and capable of influencing the interaction between the surfaces) is important in this study.

This project was directed to the study of flexible and deformable materials, in particular those that are in direct contact with the human skin, as well as to the design and development of a tribological equipment capable of meeting the requirements for these tests.

Through these tests it was possible to measure the coefficient of friction between the two materials in contact, the rubbing probe and the material sample. To accomplish the main goal, a certain number of specifications were established. Different grabbing sample systems have been studied, as well as displacement systems, control of the testing speed and probe types. Other essential conditions were considered to allow the use of an existing equipment in the Mechanical Engineering Department of the University of Minho.

Firstly, a market analysis was performed for the various types of existing tribometers and the advantages and disadvantages for this application were identified. On a second stage, the objectives tree method and the function analysis method were used. According to the objectives to be achieved and the specifications to be met, the design and analysis of various alternative solutions were undertaken to determine the best solution for the testing equipment, in a simpler, practical, economical and feasible way.

Three-dimensional representations of all the components were carried out, as well as the overall assembly of the designed tribometer, using the AutoCAD® and the SolidWorks® software packages (Planchard 2014) for their mechanical design and simulation.

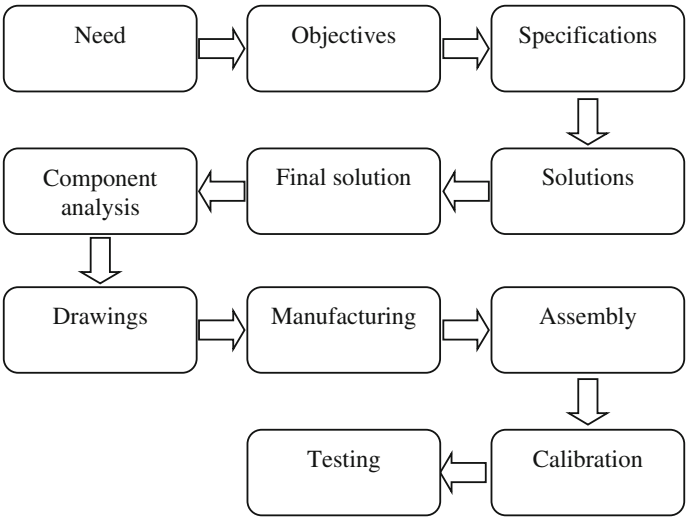

Fig. 1 Development stages of the project

A final prototype was built and assembled. The probe's displacement and velocity, as well as the potentiometric ruler, the load cell and the laser sensor for measuring the roughness of the testing sample were calibrated.

Finally, systematic tests were carried out on different samples at various speeds to demonstrate the tribometer's working principle and its feasibility.

Figure 1 shows, schematically, the different performed stages for the development of this equipment:

2 Tribometer Types

With the objective of developing a capable testing equipment, an analysis of several different types of devices available in the market was carried out.

In the field of tribology of deformable materials, various methods for friction testing are employed; the most used are the linear method and the rotary method. The following sections will be addressed to the presentation of these two methods.

2.1 Linear Method

The linear method is based on slipping a probe on a sample, or vice versa, straight and hence generating a frictional force. The friction coefficient is obtained by dividing the friction force by the normal force applied to the sample and probe set;

the static coefficient is obtained using the force required to initiate movement, while the dynamic coefficient is obtained using the frictional force required to maintain movement.

The method used in the tribometer is linear and has a pin type probe. Using this method, the sample is axially loaded by the probe and an alternate linear motion is forced between the two surfaces in contact (i.e. between the probe and the testing sample). In consequence, a frictional force opposing the displacement of the probe is developed, as shown in Fig. 2.

The friction coefficient μ is then obtained by dividing the friction force ($F_{friction}$) by the normal applied force N through the following Amontons' law of friction:

$$\mu = \frac{F_{friction}}{N} \tag{1}$$

Figure 3 represents the main components of a linear tribometer for the measurement of the friction coefficient:

Another type of study within the linear method is to obtain the friction coefficient through the resulting friction force of dragging strips on samples or even on the forearm of human volunteers.

In the study of different contact materials with the human skin, there is an equipment that has the ability to measure different materials properties (with greater focus on textile materials) using a set of multiple devices, being the most representative the so called Kawabata Evaluation System (or KES) (Kawabata and Niwa 1989; Wu et al. 2003); this system is presented in Fig. 4.

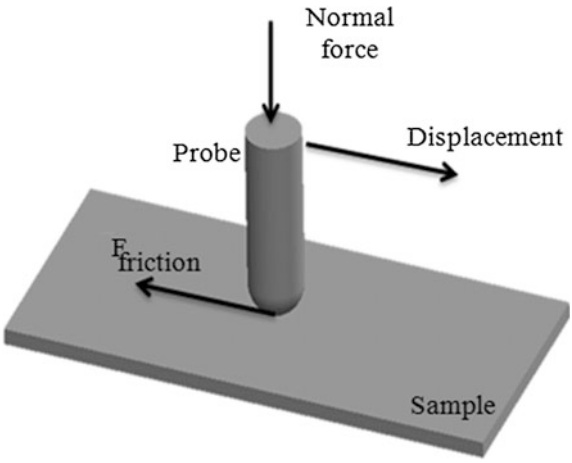

Fig. 2 Working principle of a tribometer

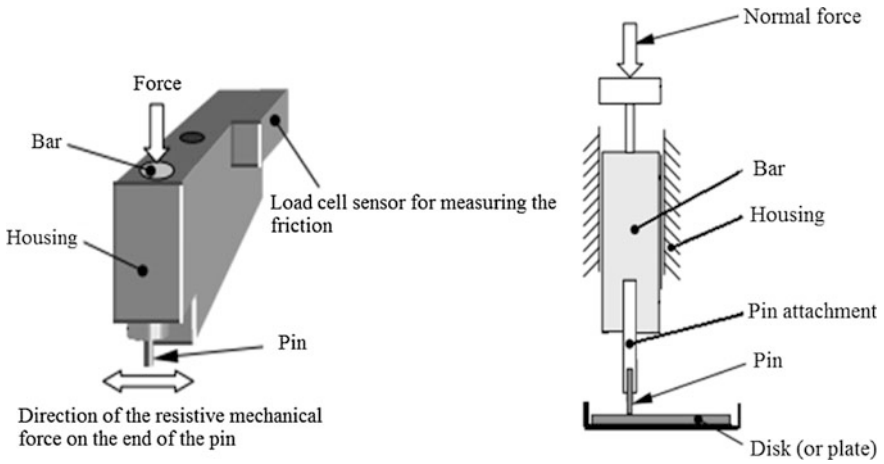

Fig. 3 Example of the measurement of the coefficient of friction in a linear tribometer

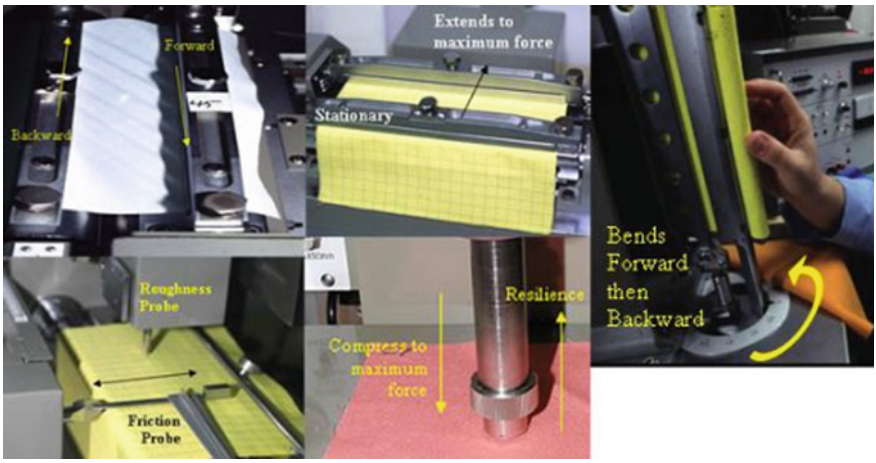

Fig. 4 The kawabata evaluation system (or KES) (Kawabata and Niwa 1989)

The KES is made up of four different equipments, which enables the following types of tests:

- Tensile;
- Compression;
- Bending;
- Friction;
- Roughness.

This testing equipment is one of the most complete in the market, however it is not widely used in industry due to its high cost.

2.2 *Rotary Method*

The rotary method uses a ring-shaped contact body (with an outside diameter D and an inside diameter d), which rotates around its axis and wherein a contact force P is applied on the sample. Its operation principle is schematically shown in Fig. 5.

The first development has led to the design of a friction test rig whose operating principle is based on a dry clutch disc, where a planar body with an annular configuration (as shown in Fig. 6) is dragged onto another flat surface, rotating around an axis perpendicular to the contact plan, under the action of a given normal force (P) resulting in an uniform distributed contact pressure. This is the principle used by FRICTORQ, which is a laboratory equipment designed to measure the coefficient of friction in fabrics and other planar flexible surfaces. It is made up by a high precision torque sensor (with a data acquisition system), a DC motor (with a gear reducer and a timing belt to drive the support of the fabric sample) and by a software application to control the whole system. The friction coefficient is then proportional to the level of torque being measured by the torque sensor.

The upper body is also designed to be a "standard" body, ensuring a certain contact pressure and linear velocity (Lima et al. 2005, 2007; Macedo et al. 2012). This upper test body is built to accommodate different types of surfaces, as depicted in Fig. 7.

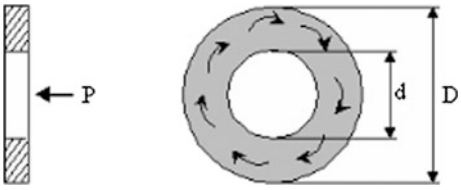

Fig. 5 A ring-shaped contact body used on a rotary method

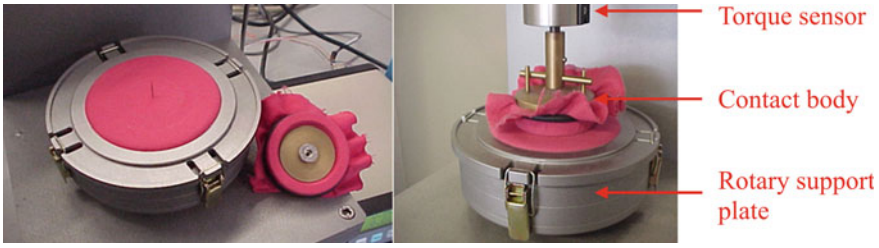

Fig. 6 The FRICTORQ equipment on a fabric-to-fabric set up

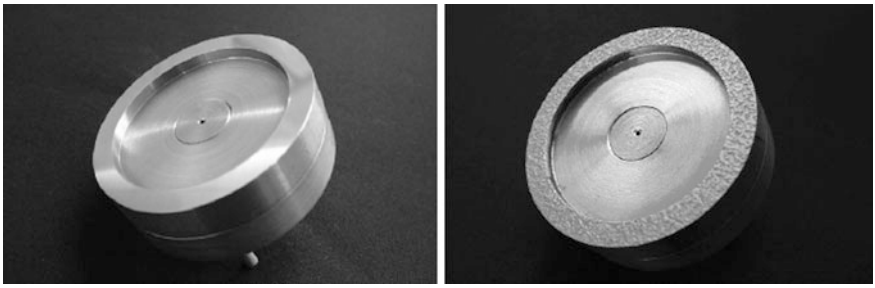

Fig. 7 A detail of the smooth (*left image*) or textured (*right image*) metallic bodies used as "standard" testing bodies

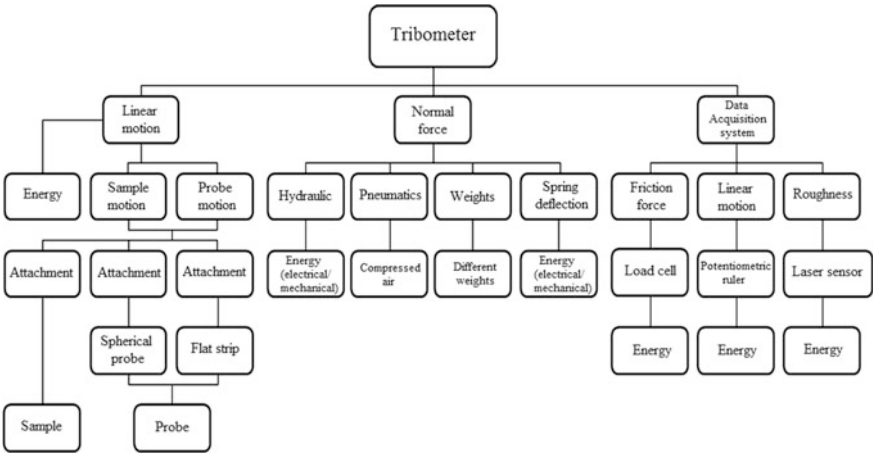

Fig. 8 A functions tree for a linear tribometer

3 Design and Development of the Linear Tribometer

As mentioned, different phases were undertaken for the design and development of a linear tribometer: the design problem was clarified, an objectives tree was established, the specifications were decided and the best solution was chosen taking into account all the established requirements.

3.1 The Objectives Tree

After market research and to further clarify the various possibilities to consider and implement for each one of the different equipment systems, a diagrammatic objectives/functions tree was drawn, as presented in Fig. 8, where each function is an objective that may be achieved by different means (sub-objectives).

Table 1 Objectives/specifications for the design and development of the linear tribometer

Description	Item
Type of tests	Measurement of the friction coefficient and of the profile of roughness
Normal force	Varying from the probe's weight to 2 kg; by gravity
Motion type	Alternative linear motion
Displacement	Varying from a minimum of 5 mm to a maximum of 280 mm
Linear velocity	Varying from 1 to 15 mm/min
Friction force and roughness measurement	Tension and compression load cell (friction force) and laser sensor (roughness)
Probe's geometry	Spherical (contact) end

3.2 Specifications

A series of initial objectives and specifications were addressed to this design. These defined which type of tribometer, sample, probe and applied forces should be used, as well as other working parameters—see Table 1.

3.3 Tests

As mentioned earlier, tribometers are capable of measuring the frictional force between two surfaces. For this particular linear tribometer it is also needed that the testing equipment is also capable of measuring surface roughness of the sample that is being tested using a laser sensor.

3.3.1 Normal Force

For the normal force, the manual application of weights was chosen mainly due to its simplicity and compactness, and because it was the most cost-effective solution. One of the main drawbacks of this loading system is the need for different calibrated weights to apply different loads, which initially involves a lower range of possible loads. This solution uses a thin glass tube (a typical lab test tube); first, the probe with the desired geometry and material is inserted, and then the successive weights to achieve the desired normal force are also added.

3.3.2 Linear Motion Between the Sample and the Probe

For this purpose a motorized linear slide table by FESTO was used with the reference TLH 300. Its movement is carried out using a DC motor and the maximum displacement is 280 mm.

3.3.3 Displacement Amplitude

The used linear slide table has two position adjustable end stop sensors that enable a working testing displacement between 5 and 280 mm.

3.3.4 Linear Velocities and Direction of Motion

The linear movement of the slide table is accomplished by means of a DC motor coupled to a 3 mm pitch power screw, allowing the change of the testing velocity and direction of the linear movement of the table, respectively, by modifying and inverting the voltage applied to the DC motor.

3.3.5 Friction Force Measurement and Surface Roughness

The friction coefficient is obtained by dividing the friction force by the normal force. The normal force is previously known, being necessary to determine the frictional force during the tests. This is measured by a load cell, reference WMCP 1000G (from Interface), being capable of measuring a maximum of (tensile and compression forces of) 1 kg_f. To measure the roughness profile/wrinkle of the sample, a laser triangulation sensor from Micro-Epsilon, optoNCDT 1302 model, was selected.

3.3.6 Probe's Geometry

The probe is the component where the normal force is applied. It is also the component that will come into direct contact with the sample. Its geometry is important in that contact so it cannot generate any other forces in directions not perpendicular to the normal force, which will influence the correct measurement of the frictional force by the load cell.

3.4 Design of the Components

The purpose of this section is the design of the main components of the linear tribometer, namely the structure and attachment of the load cell and the laser sensor. The design of the mentioned components, to accomplish their functions without collapsing and without deforming or vibrating excessively, was carried out within certain limits, which are defined by technical standards.

Therefore, the main steps of this design phase were, after the creation of the structural scheme, the definition of the forces acting on the structure and the identification of its constraints, to subsequently determine the forces and deflections.

3.4.1 Tribometer Structure

To design of the tribometer's (support) table, the actual weight of the tribometer table was applied which is approximately 8 kg_f. To perform the test, the forces were applied on top of the structure, as well as on the locations where the bottom of the structure is attached. Figure 9 shows the results of the numerical simulations carried out using finite elements.

Considering a finite element mesh of 4 mm, the maximum results obtained for deformation and stress were, respectively, 0.01 mm and 5.83 MPa. The deformation is within the limits considered and since the forces are very small, the maximum obtained stress is much smaller than the lower yield strength of all the used materials.

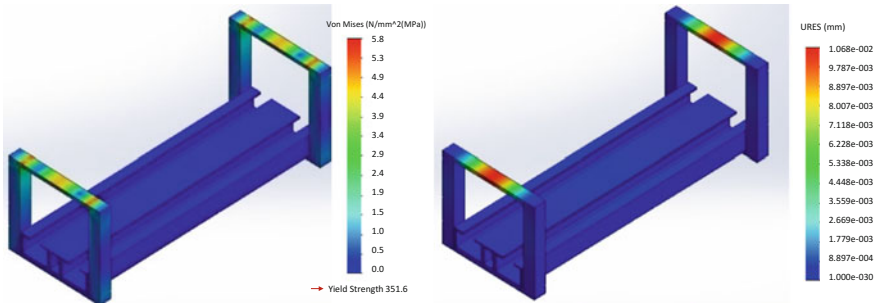

Fig. 9 Results obtained in a simulation with a force of 78.5 N

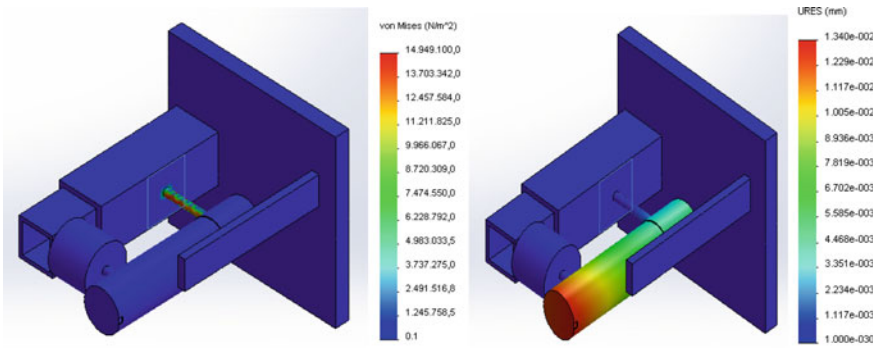

Fig. 10 Results obtained in the simulation with the load cell attachment

3.4.2 Design of the Attachment System for the Load Cell, Probe and Laser Sensor

This system is responsible for the attachment of the electronic components, such as the load cell (which will measure the frictional force generated by sliding of the probe over the sample at a given normal force). This movement will generate tensions in this support base. Considering the same finite element mesh of 4 mm, the maximum deformation and stress were, respectively, 0.013 mm and 15 MPa. The deformation is within the limits imposed and, again, since the forces are very small, the maximum obtained stress is much smaller than the yield strength of the used material. Figure 10 shows the obtained results.

3.5 Construction of the Tribometer Prototype

After the conclusion of the conceptual, preliminary and detailed design phases, the construction and assembly of the tribometer prototype was undertaken. Figure 11 shows the testing apparatus of the built linear tribometer, as well as the entire implemented command and control systems (hardware and software). After the conclusion of this phase, a preliminary test validation of the tribometer was performed.

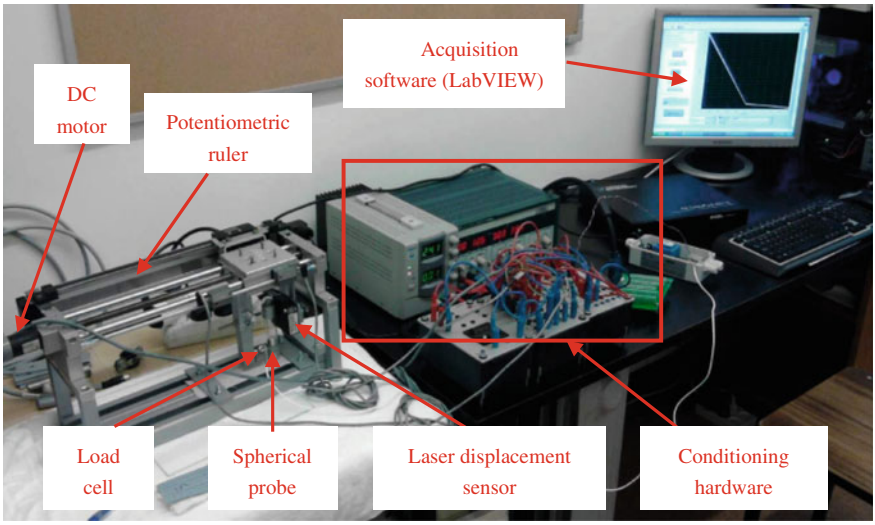

Fig. 11 Overall view of the developed linear tribometer

4 Validation Tests

After all the phases previously described and after the calibration of the different components to make this a reliable tribometer, validation tests were performed to the testing equipment (values of the coefficients of friction) using six samples of textile fabrics.

To prove that the linear tribometer was providing reliable data, it was decided to compare the obtained results using the set up parameters and criteria (in terms of velocity, displacement, sample type and normal forces) to carry out tests with the same conditions on a different tribometer, namely, the FRICTORQ testing equipment previously mentioned.

Due to the fact that FRICTORQ uses the rotary method and the proposed design uses a linear one, the linear velocity in the contact had to be determined using the angular velocity of the FRICTORQ; a tachometer was used to measure 0.7 rpm, and knowing that the average radius of the test probe body (see again Fig. 7) is 21 mm, the equivalent linear speed is 92.4 mm/min, i.e. the velocity to be applied to the linear tribometer. Another important parameter was the distance traveled by the probe: the distance should be similar. The FRICTORQ was considered as reference, because the linear tribometer is the only one capable to adjust the distance travelled by the testing probe. Then, the distance travelled by the probe was determined, which is the perimeter corresponding to the FRICTORQ mean contact circumference (131.8 mm). A probe with a mass of 25 g was used in the linear tribometer, to replicate the same conditions as in the FRICTORQ.

Figure 12 highlights the samples chosen to determine the friction coefficient of six different textile fabrics, each of which was subjected to two tests corresponding to a total of twelve tests on each of the two tribometers (in a total of twenty-four tests).

Initially the tests were carried out on the FRICTORQ, due to its inability to control variables, such as, velocity, displacement and height of the sample relative to the linear tribometer. After their observation and using similar test conditions (in terms of samples, velocity, displacement and normal force) it was possible to carry out the same tests in the linear tribometer.

Figure 13 shows the main results for the obtained coefficient of friction obtained with both tribometers. Analyzing the results, it can be seen that in both tribometers the coefficient of friction average values are real close: the biggest difference was observed in sample 2 (0.05) and equal results have been found for sample 5. In

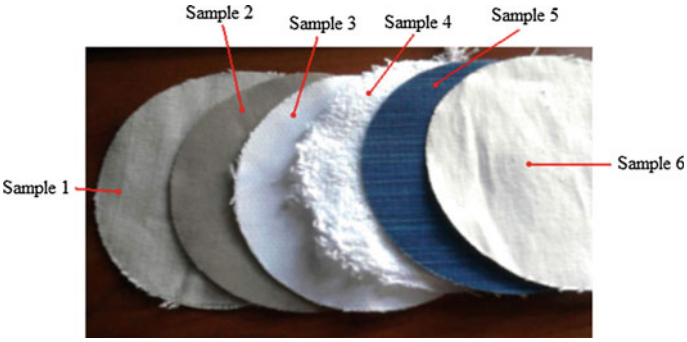

Fig. 12 Six different textile fabrics tested on the linear tribometer

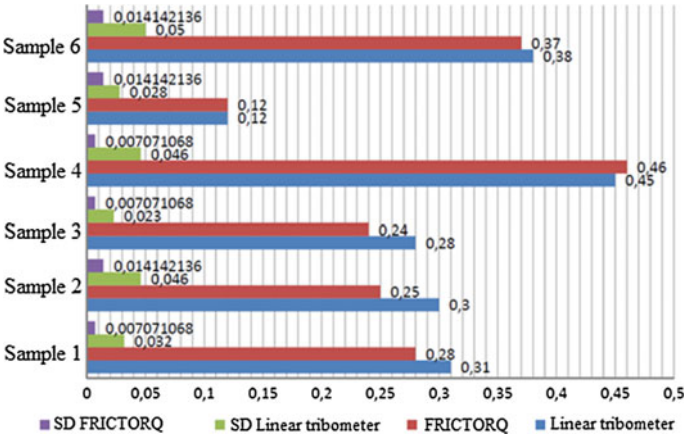

Fig. 13 Results obtained for the coefficients of friction of the six textile fabrics tested

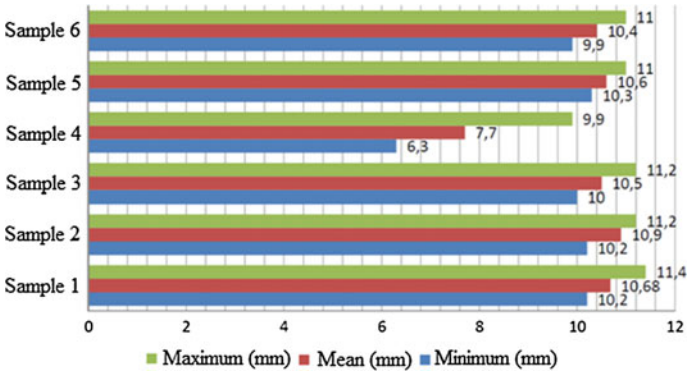

Fig. 14 Results obtained for the roughness of the six textile fabrics tested

terms of standard deviation (SD), it can be noticed that there are some differences between the results obtained with the two tribometers: this can be explained by the differences between the data acquisition systems (different acquisition rates). Although in both tribometers the SD is low, the biggest value was 0.05 in sample 6, with the linear tribometer, and 0.01 in samples 2, 5 and 6 with the FRICTORQ.

In order to determine if there is a correlation between the results obtained for the friction coefficients (see Fig. 13) and the roughness of the samples, Fig. 14 shows the roughness values measured by the laser sensor attached to the linear tribometer.

Sample 4 is the one that shows a more evident correlation, because it is the sample with the higher coefficient of friction, and with the greater surface roughness (higher range of values). Sample 5 is the sample that has a lower coefficient of friction, as well as a lower roughness (range of values). The remaining samples (1, 2, 3 and 6) are very similar, in terms of coefficient of friction as well as in terms of roughness.

Thus it can be concluded for the tested fabrics that there is a relationship between surface roughness and the coefficient of friction of a material, i.e. the greater the range of roughness values, the higher is the coefficient of friction of such material.

5 Conclusions

Regarding the design and development of a new linear tribometer for testing the human skin, it was possible to create a suitable, versatile and feasible equipment that meets all the required specifications.

The new linear tribometer herein proposed was validated comparing its results for the coefficient of friction with the ones measured under similar conditions in an existing tribometer. The results suggest and demonstrate the reliability and accuracy of the data obtained by the developed linear tribometer.

Future work will be directed to the optimization of the acquisition and control systems of the linear tribometer and more validation tests will be undertaken using other types of materials, in particular silicone laminates that simulate human skin.

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3D Myocardial Modelling by Computational Geometry Techniques. Analysing Performance

F. Cavas, F.J.F. Cañavate, J. Nieto and D.G. Fernández-Pacheco

Abstract The first cause of death in Spain is cardiovascular diseases, with a death rate of 30.3% according to the latest mortality data published by INE (Spanish National Statistics Institute). In this scenario, it is necessary to develop powerful computer tools capable of predicting, among others, mechanisms of performance of heart muscles with certain pathologies. The present work proposes a 3D myocardial geometry reconstruction procedure that employs computational geometry techniques to later simulate mechanical myocardial performance under normal ventricular load and stenosis conditions. The variability in the obtained responses allows the disease to be characterised by defining a new approach, used to diagnose this pathology by solid biological structure modelling.

Keywords Computational geometry · 3D modelling · Finite elements · Biomedicine

1 Introduction

Constant demand for new clinical diagnostics equipment and medical instruments, due to prolonged life expectancy, means that medicine is continuously developing and evolving. All this involves the constant need to rely on increasingly effective and efficient diagnostics techniques to obtain the best results from assisted treatments (Cunha et al. 2014).

Applying technologies developed in the world of engineering to the field of medicine, which is known as bioengineering, implies the possibility of analysing certain pathologies on a personalised basis. One particular case is to use a simulation software tool based on the numerical Finite Element Method to characterise the biomechanical performance of a biological structure with a given pathology,

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and to subsequently treat it with invasive or non-invasive techniques (Lohfeld et al. 2005).

Acquiring a real geometric model of the biological structure to be analysed to obtain reliable results is one of the main limitations of biomechanical models.

Real tissue geometry is accomplished from a series of internal tensions; e.g. due to growth, remodelling, damage or deformations that develop throughout life, and to external actions to which tissue is submitted given its relation with the environment and the rest of the human organism (Fung 1993).

In this case, bioengineering resorts to the reverse engineering concept (Lopez-Herrejon et al. 2015) to facilitate the difficult process of geometrically recognising the contour of a biological structure of a given patient (Cavas-Martínez et al. 2014), for it to later act as a base model to biomechanically analyse the structure according to the Finite Element Method (Ariza-Gracia et al. 2015).

The geometric modelling of biological structures has progressed considerably thanks to the link to improved techniques that produce X-ray images, CT, magnetic or ultrasound resonance, as a tool to fundamentally support clinical diagnoses (Cunha et al. 2014). With these images, and after previously processing them with specific software, data can be obtained as clouds with spatial points to then generate both the geometric surface and the model that constitutes the structure's contour by means of computational geometry techniques (Sekar et al. 2008). The generated solid model acts as the geometric basis for subsequent biomechanical analyses.

The first cause of death in Spain is related to cardiovascular diseases, with a rate of 30.3% according to the latest mortality data published by INE (Instituto Nacional de Estadística 2015). This cardiovascular system is made up of the heart and blood vessels; the former operates as a force-lifting pump, while the latter make up a network of tubes that transport blood to and from the heart (Mahadevan 2015).

In cardiovascular medicine, a pathology called heart failure occurs when the heart cannot pump the amount of blood that the human body requires (Mahadevan 2015). The signs that indicate this pathology have an implicit biomechanical component; that is, both the heart (asynchrony, valvular dysfunction, etc.) and the vascular system and blood (increased viscous resistance, etc.), which affect the heart working mechanically like a pump (Lindop 2007).

This pathology comes in several stages according to its degree of progression. The most critical stage affects the heart muscles in charge of cardiac contraction, which is known as myocardial infarction. This is due to the narrowing of a conduct (stenosis), which occurs in coronary arteries as a result of cells, connective tissue or lipids being deposited or accumulating there. Such alterations increase pressure in the heart's cavities, particularly in ventricles which, in more advanced cases, can stop the heart or lead to infarction (Doucet and Burwash 2015).

For these reasons, this communication focuses on analysing the biomechanical performance of heart muscle tissue (myocardium) with several degrees of stenosis.

2 Objectives

The present communication initially proposed obtaining a real geometric model of the myocardium by means of computer tools based on either a computer-aided geometric design or computational geometry. Obtaining the geometric domain of the series based on functional parametric surfaces began and was feasible thanks to the versatility they offer in virtual 3D settings.

Finally, numerical simulation was carried out by the Finite Element Method to biomechanically analyse the myocardium with several degrees of stenosis.

3 Methodology

This section describes the two modelling methods employed in the present communication.

3.1 Modelling the Myocardium by Computational Geometry

The representative geometric domain of the myocardium anatomy is obtained by previously acquiring the parts that constitute it: the external ventricular part of the heart, atria, pulmonary and aorta arteries, and the left and right ventricular cavities. They were all obtained by a reconstruction procedure, which was based on processing medical WDS images, this being a widespread standard in heart surgery. Given the structural complexity of heart tissue, a criterion was adopted to define the geometry of it being made up of a single tissue with uniform properties. The solid model was then reconstructed with computer-aided geometric design—(CAGD) based software tools.

The procedure used to obtain the geometric ventricular contour consisted in:

1. Obtaining the contour and borders of the biological structure that defines tissues according to the definition for Splines curves on a medical WDS image. CorelDRAW Graphics Suite X6 graphic was used for this purpose. Having defined the outer contour, the operation was repeated to define the smallest contours that corresponded to each heart cavity, valve and artery. A geometric slicing approach (slices) was adopted by means of Splines curves.
   Splines functions were used to reconstruct the parametric surfaces, which were polynomial curves where the polynomial change occurred in the partition of the parametric interval, known as a node (Sekar et al. 2008).
2. Importing Splines curves to the Rhinoceros v4 solid modelling software to generate the geometric surface of the 3D model by interpolating previously

defined curves. The use of computational geometry-based software is essential for modelling the biological shapes that present complex irregularities in their contour. The virtual setting was where the apex was taken as a reference at the coordinate origin, and the highest point was about 13 cm high. The geometrical shape of the model obtained in the virtual setting was similar to that of the heart (see Fig. 1).

This operation was repeated up to 7 times to obtain the seven independent solid models that made up the myocardium morphology: first the external ventricular structure of the heart was modelled (Fig. 1). Then two other solid models were modelled, which made up the part of the sections that corresponded to the atria (Fig. 2). The next two, corresponded to the inlets of the pulmonary and aorta arteries. The last models belonged to the cavities that corresponded to the right and left ventricles.

All the obtained models were assembled in their anatomical position and were submitted to a Boolean algebraic structure that schematised logic operations, and a series of operations, e.g., union, intersection and complement among solids, to correctly define the ventricular cavities, the inlets to the two atria, and the pulmonary and aortic arteries (Fig. 3).

The final solid geometric model represented a heart muscle tissue structure, the myocardium, which well resembled the real thing.

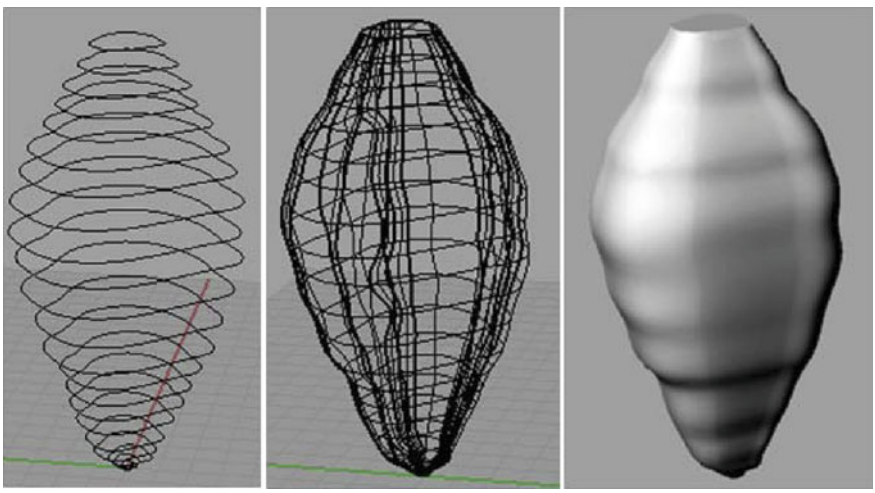

Fig. 1 External ventricular structure. Solid modelling by computational geometry

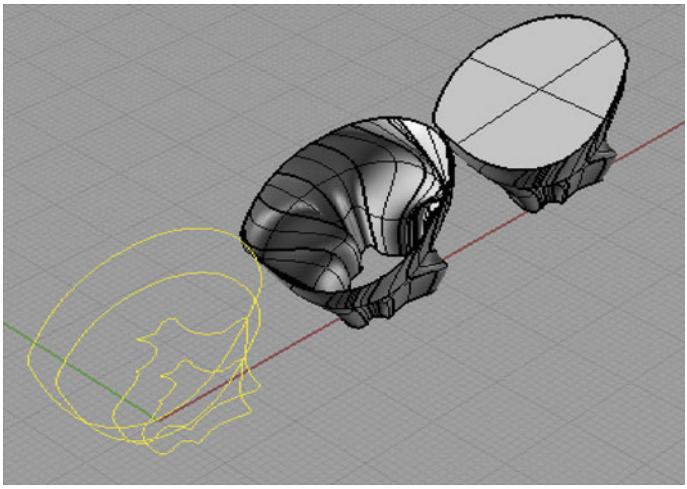

Fig. 2 Atrium. Solid modelling by computational geometry

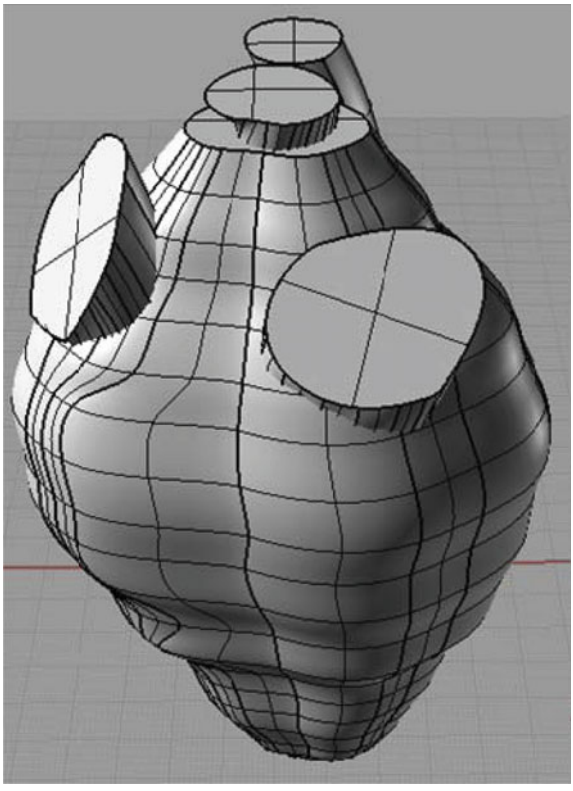

Fig. 3 Myocardium. Solid modelling by computational geometry

3.2 *Biomechanical Myocardium Modelling by the Finite Element Method*

In addition, the generated geometric model of the myocardium was exported to a specific finite element software, ANSYS v12.0, to numerically simulate the distribution of efforts, displacements and deformations that occur in the system in accordance with several degrees of stenosis (Fig. 4).

Narrowing in arteries caused by stenosis can alter bloodstream flow through increased pressure on heart ventricles which, in extreme cases, can cause myocardial infarction.

The Finite Element Method is a numerical method that solves contour problems ruled by ordinary or partial differential equations. The idea is to replace the differential problem with another algebraic-type one by subdividing a region in which the equations of simple geometric shapes are defined, called finite elements.

Prior to the numerical simulation, the following must be defined:

- Parts that make up the system and their positions in relation to the only reference system. This communication considers only the heart tissue structure, the myocardium, and does not contemplate other parts of the heart structure, e.g. valves, pericardium and endocardium.
- The system's mechanical properties. The biomechanical performance of the myocardium is considered linear and isotropic (Table 1) (Bronzino and Peterson 2014).

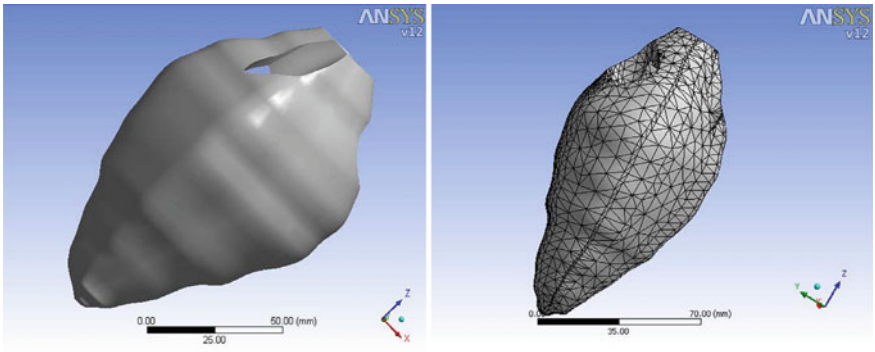

Fig. 4 Myocardium. Modelling imported to finite element software

Table 1 Average mechanical characteristics of the myocardium

	Young module (kPa)	Poisson coefficient
Heart muscle	100	0.45

- Conditions of the border and the loads system. From the biomechanical perspective, ventricular pressure is the most important border condition. The loads system to consider with the border condition data was stenosis of 0, 20 and 30%.
- The finite element used to discretise and mesh the model. Here, 13,854 tetrahedral elements were taken, made up of four nodes with three degrees of freedom each for 23,654 nodes.

4 Results

This section describes the results obtained according to degrees of stenosis (0, 20 and 30%).

4.1 Arterial Stenosis (0%)

For the first case, and according to the defined biomechanical model performance, it was necessary to know the maximum pressure of the ventricular walls. This information was obtained by simulating the bloodstream flow values for a value of 0% stenosis (Bronzino and Peterson 2014); that is, no coronary artery narrowing (Table 2).

In this case, the maximum pressure on ventricular walls was 1.58×10^{-2} MPa. The obtained displacement values were around 3 mm (Fig. 5a). The greatest displacement took place in the right ventricle area, where there is less muscle tissue than in the left ventricle, and also in the apex area of the heart. Displacement values of 3.34 mm were obtained in these areas. Maximum deformation was 0.632 mm mm^{-1} in the right ventricle area (Fig. 5).

Table 2 Myocardium (0% stenosis). Pressure values on ventricles

Time (s)	Pressure (MPa)
0	1×10^{-3}
0.1	1×10^{-3}
0.2	1.9×10^{-3}
0.3	1.44×10^{-2}
0.4	1.58×10^{-2}
0.5	1.40×10^{-2}
0.6	1×10^{-3}
0.7	1×10^{-3}
0.8	1×10^{-3}
0.9	1×10^{-3}
1	1×10^{-3}

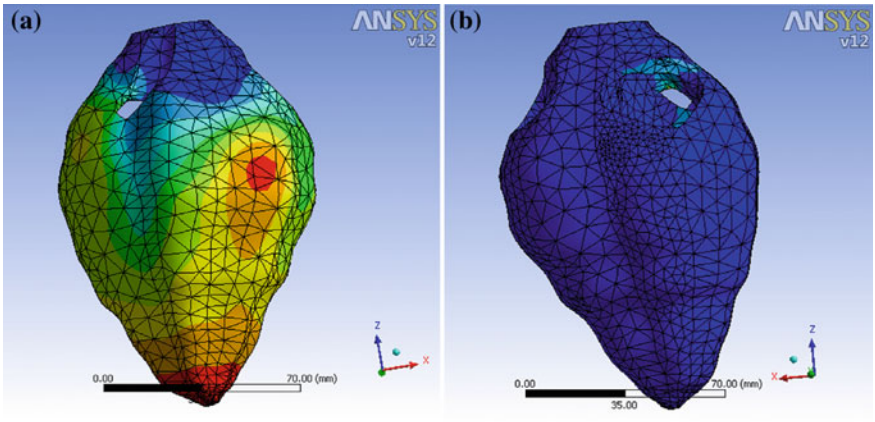

Fig. 5 Myocardium (0% stenosis): **a** displacements in the geometric model; **b** Von Mises equivalent deformations

Table 3 Myocardium (20% stenosis). Pressure values on ventricles

Time (s)	Pressure (MPa)
0	1×10^{-3}
0.1	1.6×10^{-3}
0.2	2×10^{-3}
0.3	1.44×10^{-2}
0.4	1.93×10^{-2}
0.5	1.45×10^{-2}
0.6	2×10^{-3}
0.7	2×10^{-3}
0.8	2×10^{-3}
0.9	2×10^{-3}
1	2×10^{-3}

4.2 Arterial Stenosis (20%)

For the second case, the maximum pressure on ventricular walls was obtained by simulating the bloodstream flow values for a 20% stenosis value (Bronzino and Peterson 2014); that is, coronary artery narrowing (Table 3). This implied increased flow and, consequently, increased pressure.

In this case, the maximum pressure on ventricular walls was 1.93×10^{-2} MPa. The displacement values were around 6 mm (Fig. 6a). The greatest displacements occurred in the right ventricle and apex areas, where displacement values of 6.28 mm were obtained. The maximum deformation value was 1.252 mm mm^{-1} and the maximum stress value was 0.125 MPa. Both were obtained in the right ventricle area (Fig. 6).

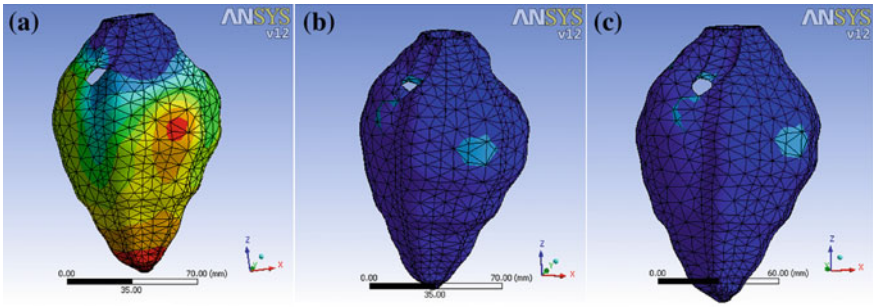

Fig. 6 Myocardium (20% stenosis): **a** displacements of the geometric model; **b** Von Mises equivalent deformations; **c** efforts

Table 4 Myocardium (30% stenosis). Pressure values on ventricles

Time (s)	Pressure (MPa)
0	7.9×10^{-3}
0.1	1×10^{-2}
0.2	1.06×10^{-2}
0.3	1.4×10^{-2}
0.4	2.1×10^{-2}
0.5	1.5×10^{-2}
0.6	9×10^{-3}
0.7	8.4×10^{-3}
0.8	9×10^{-3}
0.9	9×10^{-3}
1	9×10^{-3}

4.3 Arterial Stenosis (30%)

For the third case, maximum pressure on ventricular walls was obtained by simulating the bloodstream flow values for a 30% stenosis value (Bronzino and Peterson 2014); that is, more marked coronary artery narrowing (Table 4). This implies a more marked increase in blood flow, and consequently in pressure.

In this case, the maximum pressure on ventricular walls was 2.1×10^{-2} MPa. The obtained displacement values were around 30 mm (Fig. 7a), which are very high considering the heart's geometry. The maximum deformation value was 15.572 mm mm^{-1}, with a maximum stress value of 0.563 MPa. Both were obtained in the right ventricle area (Fig. 7).

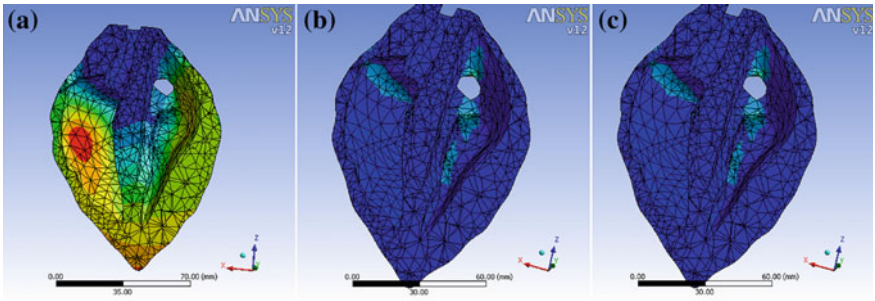

Fig. 7 Myocardium (30% stenosis): **a** displacements of the geometric model; **b** Von Mises equivalent deformations; **c** stresses

5 Conclusions

The latest bioengineering advances allow specialists to treat certain pathologies on a personalised basis. In heart surgery, knowing how the myocardial heart muscle tissue of a given patient performs in a natural and/or pathological scenario is interesting, especially one in which pressure on the myocardium increases due to artery narrowing through deposits of lipids or similar products. This pathology is known as arterial stenosis.

When it comes to defining and characterising the biomechanical performance model, knowing the real geometry of the patient under study is essential. This is precisely the reason for the present communication, which is based on the reverse engineering concept. It defines a 3D geometric myocardium reconstruction procedure by computational geometry techniques to subsequently simulate myocardium performance under normal ventricular load conditions within a stenosis percentages range.

The presented model is useful for cardiologists and can help them know the maximum numerical values of displacements, stresses and deformations, and identify possible points or areas of rupturing according to certain degrees of stenosis.

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Part IV
Environmental Engineering and Natural Resource Management

Study of the Energy Recovery of the Reject Materials from Municipal Solid Waste Treatment Plants in Spain

I. Sánchez-López, A. Gallardo and N. Edo-Alcón

Abstract In 2012, 21.2 million metric tons of municipal solid waste were collected in Spain (MAGRAMA 2014), of which 85% corresponds to mixed waste. This is then treated in different plants with the aim of recovering materials for their subsequent recycling and the transformation of the biodegradable organic fraction into compost and biogas. However, of the total amount of material processed in these plants, 42.2% is rejected. In Spain, there are 10 energy recovery plants. In 2012, only 13.57% of the total amount of the rejected material was processed in these plants. The rest was deposited in landfills. Therefore, a significant amount of the material is rejected, and is not currently exploited. The aim of this work is to analyze, on the one hand, the potential energy recovery of the material rejected from the municipal solid waste plants in energy recovery plants, by studying the energy efficiency of the existing plants. On the other hand, it will also compare different energy valorization technologies in order to analyze the need for new Waste-to-Energy plants to take advantage of all the rejected biofuel material generated in Spain.

Keyword Energy recovery · Municipal solid waste · Rejects · Incineration · Gasification

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1 Introduction

What in most traditional societies was considered simply as rubbish, is conceptualized in modern societies as waste. This shift is a result of the recognition of the potential of these materials to be used productively. Of the total amount of waste generated, this article has focused on municipal solid waste (MSW), that is, the one coming from homes, shops, offices, services and the like. Among the many forms of exploitation, thermal processes are presented as an interesting alternative (Van Paasen et al. 2006).

Due to the Spanish energetic situation, where the main energy sources are based on the use of coal and oil, which is not renewable energy, it is important to promote renewable energies such as the combustible fraction of MSW.

In order to obtain products from MSW which have some economic interest, while at the same time minimizing the discharge, it can be subjected to various treatment processes. Depending on the objective set out in the integrated management plans, the most appropriate alternative treatment option is chosen. There are mechanical treatments to separate recyclable materials; biological treatment based on the anaerobic conversion of organic waste to obtain biogas (biomethanation) and aerobic conversion to produce compost (composting). In all these treatments, a reject stream appears and its ultimate destination is the landfill. These rejects are mainly composed of materials with a high energy content, thus presenting a theoretically high potential for use as alternative fuels in industrial thermal processes or in Waste-to-Energy (WtE) plants. This valorization can be done directly or via its transformation into a solid recovered fuel (SRF). The most widely utilized thermal processes are incineration, pyrolysis, gasification and plasma (Elias et al. 2005; Bayard et al. 2010).

Thermochemical treatment processes are an essential component of an integrated MSW management system, as confirmed by numerous studies and analyses (Brunner et al. 2004; Porteous 2005; Psomopoulos et al. 2009). Their main advantages are: (a) a great reduction of the waste by mass (about 80–90%), (Consonni et al. 2005); (b) radical space savings, since much less space is needed in a landfill for the same amount of MSW. Psomopoulos et al. (2009) estimated that a WtE plant that processes 1 Mt/year for 30 years requires less than 100,000 m^2 of space, compared with the 300,000 m^2 which would be required to dispose of 30 Mt of MSW in a landfill; (c) destruction of organic contaminants, such as halogenated hydrocarbons (Mckay 2002; Buekens; Cen 2011); (d) concentration and immobilization of inorganic contaminants, which can be treated and disposed of safely (ISWA 2008; Samaras et al. 2010); (e) recycling of ferrous and non-ferrous metals from ashes and slag (ISWA 2006; CEWEP 2011); (f) reduction of emissions of greenhouse gases from the anaerobic decomposition of organic waste. Psomopoulos estimated that a reduction of 1 metric ton of CO_2 equivalent is achieved per metric ton of waste if it is processed thermally rather than depositing it in landfills; and (g) prevention of environmental burdens (Arena et al. 2003;

Azapagic et al. 2004), as the regulations regarding emissions are much more severe compared to other sources of energy.

In Spain, incineration technologies are mostly used. These have been developed for different types and physical forms of waste, some of the more frequent being liquid injection designs, rotary, fixed furnaces and fluidized beds (Opel 1986; Kisuk 1998). Currently there are 10 MSW WtE plants, where 13.57% of all the rejected material generated in 2012 was processed. The rest was deposited in landfills, therefore, a significant amount is wasted. Furthermore, as in most of Southern Europe, these are conventional thermoelectric plants, i.e., they only generate electricity in the processing of waste. This fact makes it difficult to achieve the values set by EC Directive 2008/98 on waste (Waste Framework Directive) regarding energy efficiency and they can therefore be categorized, in accordance with Annex II of the Directive, as R1 plants, i.e., as having an energy recovery status.

2 Objective

The aim of this paper is to analyze, on the one hand, the current situation of MSW treatment in Spain and the potential energy contained in the rejected materials from the different MSW treatment plants. On the other hand, it also intends to conduct an analysis of the performance and capacity of these rejects in WtE plants. To this end, different bibliographical sources have been reviewed and studied, to enable the analysis of the regulatory framework and the parameters that determine energy efficiency under the regulations concerning WtE plants. A comparative analysis among different plants was also performed.

3 Current Situation of the Treatment of MSW in Spain

The study focused on the year 2012, since this is the last year for which complete data are available. That year 21.2 million metric tons of MSW (MAGRAMA 2014) were collected, of which 18 million corresponded to mixed waste. The rest was collected separately. Of the total amount of waste, 63% was treated in different facilities (Fig. 1), 27% was deposited directly in landfills, and 10% was incinerated (Eurostat 2012). The waste is treated in these facilities according to the fraction to which it belongs so as to be able to reuse and recover materials by recycling, as well as to transform biodegradable organic waste into compost and biogas (Colomer and Gallardo 2007). However, of the total material processed in the different facilities (12.5 million metric tons), a very significant amount is rejected. This rejected material is mainly composed of combustible material (Gallardo et al. 2014).

Rejected material flows vary depending on the type of treatment plant. Thus, the rejection rate of each plant is 42.33% for light packaging plants (LPP), 37.03% for

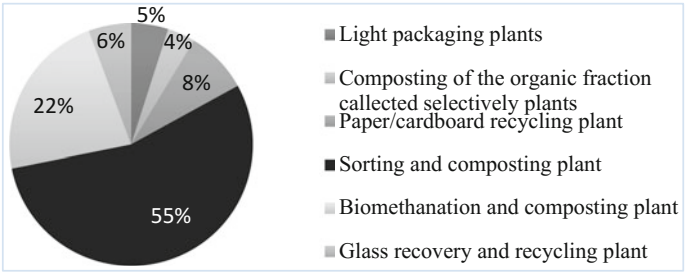
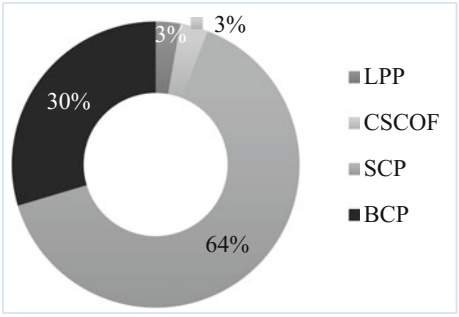


Fig. 1 Percentage of the incoming material at MSW treatment plants in Spain, 2012

Fig. 2 Reject materials from MSW treatment plants, 2012



composting of the selectively collected organic fraction (CSCOF), 60.99% for sorting and composting plants (SCP) and 75.38% for biomethanation and composting (BCP) (MAGRAMA 2014; Edo 2012). In 2012, the total amount of reject material from MSW treatment plants was 7.8 million metric tons, thereby accounting for 61.82% of the total amount that was processed. The greater part of all the reject materials came from the SCP (Fig. 2).

Continuing with the analysis of the MAGRAMA data, with respect to the total amount of reject materials generated in these plants, only 13.57% of the nearly 8 million metric tons entered WtE plants. The remaining reject, 86.43%, was sent to landfills, which represents 47.79% of all the material they received.

To determine the feasibility and performance of the WtE plants for both mass waste and reject materials, it is essential to determine their calorific value. Depending on the type of treatment plant, the composition of the reject will be higher in some fractions than in others, and therefore they have a different calorific value.

Table 1 (Edo 2012), shows the lower heating value (LHV) of the different fractions that may be present in the reject materials of MSW treatment plants. Most of the LHV values are quite high when compared to other fossil fuels such as anthracite, with 6700 kcal/kg, or lignite, with 2177 kcal/kg.

By way of example, Edo (2012) determined the LHV of an LPP, the result being 3883.87 kcal/kg, calculated on dry matter.

Table 1 LHV of the MSW fractions in dry matter

Fraction	LHV (kcal/kg)
Paper/cardboard	2658.00
Mass waste[a]	2600.00
Textile/cellulose	3929.34
Plastic film	8344.57
Rigid plastic	7182.55
Wood	3393.09
Organic matter	2810.47
Cork	8303.37
Rubber	3931.22
Polyurethane	6057.29

[a]Data estimated by Grau and Farré (2011)

If, furthermore, the reject materials from different MSW treatment plants are processed to be transformed into an SRF by mechanical treatments (grinding, drying, removal of metals, etc.), it is possible to obtain a fuel with homogeneous and well-defined properties. For example, in the case of rejects from an SCP, an SRF with an LHV between 5600 and 6100 kcal/kg can be obtained (Gallardo et al. 2013).

From the data analyzed, it is possible to estimate the energy potential of the reject materials generated by MSW treatment plants in Spain for the year 2012 (7.8 million metric tons). If one considers that these rejects are used as mass waste (2600 kcal/kg), then 84,631,600 GJ are obtained from the potential energy contained in them. For the same year, taking into account an average LHV of 5800 kcal/kg (Gallardo et al. 2013) and considering that 28% of the material is lost during processing of SRF makes it possible to obtain a total of 188,793,571 GJ of potential energy contained in them.

4 Current State of the Energetic Valorization of MSW in Spain

The Directive 2008/98/EC of the European Parliament and of the Council on waste (Waste Framework Directive) accepts the incineration of MSW as an energetic valorization of waste operation provided that minimum energy efficiency is achieved. This lower limit is given by the R1 Formula (Eq. 1), to which reference is made in its Annex II, on recovery operations (R for recovery). If the minimum values required regarding energy efficiency (0.60 for installations in operation and permitted in accordance with applicable community legislation before 1 January 2009, or 0.65 for installations permitted after 31 December 2008) are not achieved, this process will be considered a disposal operation, thus being categorized as D10 (D for disposal), according to Annex I of the Directive.

These requirements of an energy efficiency of 0.60 and 0.65 mean that the equivalent energy produced by WtE plants is at least 60% or 65% of the energy that a classical plant which burns conventional fuels would produce, either in the form of electricity or heat.

$$EE = (Ep - (Ef + Ei))/(0.97 \times (Ew + Ef)) \quad (1)$$

where

- Ep: means the annual energy produced as heat or electricity, which is calculated by multiplying the energy in the form of electricity by 2.6 and the heat produced for commercial use by 1.1 (GJ/year). The 2.6 factor for electricity is based on a value of 38% of a European average coefficient of coal-fired plants, which means an energy demand of 2.6 kWh to produce 1 kWh of electricity. The 1.1 factor for heat generation is based on a value of 91% of a European average coefficient of heat generating plants.
- Ef: is the annual energy input to the system from fuels contributing to the production of steam (GJ/year).
- Ew: is the annual energy contained in the treated waste calculated using the net calorific value of the waste (GJ/year).
- Ei: is the energy imported annually, excluding Ew and Ef (GJ/year).
- The 0.97 factor represents energy losses due to bottom ash and radiation.

It can be seen how, in the R1 Formula, the term Ep (energy produced) is subtracted by "(Ef + Ei)", indicating that the external supply of energy for the process is counterproductive when it comes to complying with the values for minimum energy efficiency.

The R1 Formula is used to determine the efficiency of the system for recovering energy contained in waste and generating electricity, heat or steam.

In this regard, in a study on the efficiency of the WtE plants in Europe, Reimann (2009) classified plants according to three criteria:

- Generation type: only electricity, only heat or cogeneration (electricity + heat).
- Plant size: small, medium or large.
- Geographical location: Southern Europe, Central Europe or Northern Europe.

Thus, the plants with poorer outcomes in terms of energy efficiency are those only generating electricity. This is because the transformation into electrical energy with respect to the LHV of waste varies between 20 and 30% due to losses in the exhaust gases by radiation, in ash and in slag. However, the thermal energy available is 75% of the energy input into the process. In turn, this thermal energy can be converted into electricity with an efficiency of around 30% by using exhaust steam turbines (Romero 2010). This is important, since the vast majority of the plants in Southern Europe generates only electricity, and would therefore be giving priority to plants from colder climates, which have a heat demand, in the form of either hot water or heating, that is much higher than in areas with warmer climates.

Reimann also found a series of conditioning standards that must be met so that a WtE plant exceeds the values of energy efficiency without any problems. These are as follows:

- The WtE plant must be connected to a heat distribution network, which is rare in Southern Europe.
- Ensure a stable and continuous heat demand, since it is not possible to store it. In any case, for the energy recovery process to be efficient, it must be both continuous and stable.
- The plant should be located in urban areas or in close proximity to urban centers or industrial estates so as to be able to output the heat that is generated.

In 2012 the Joint Research Centre of the European Commission, issued a report (Energy recovery Efficiency in Municipal Solid Waste-to-Energy plants in relation to local climate conditions), which states that:

- Weather conditions significantly influence the amounts of energy that can be produced or used in the form of electricity, heat or steam.
- To equate WtE facilities affected by local climatic conditions, it is reasonable to apply a climate correction factor (CCF) to the R1 Formula.
- The CCF should be based on both the document regarding best available techniques for waste incineration and local climatic conditions.

This has led to a draft being drawn up with amendments to Annex II of the Waste Framework Directive, which takes into account the CCF. The application of this factor would mean some incineration plants categorized as D10, would reach the threshold of the R1 Formula and thus become R1 facilities.

5 Analysis of the Waste-to-Energy Plants in Spain

In 2012 the total input of MSW at the 10 WtE plants in Spain was 2.1 million metric tons, of which 1.04 million metric tons were mass waste and 1.06 million metric tons consisted of reject materials, according to MAGRAMA, 2014.

Table 2 shows the location of these facilities, their capacity and the power output generated. It can be seen that the plant with the highest capacity is in the Autonomous Community of the Balearic Islands, since it has four furnaces. However, the plant in the Autonomous Community of the Basque Country (Zabalgarbi) is the one that generates the most power because it is a special plant, since incineration is integrated within a combined cycle together with natural gas. This fact allows it to work with steam parameters that are different from those of a conventional WtE, and more advantageous from the standpoint of thermodynamic efficiency and levels of corrosion in pipes (BREF-WI, pp. 311–313). At the same time, Catalonia is the autonomous community with the most plants and a treatment capacity of around 700,000 metric tons/year. All the plants appear in the

Table 2 Distribution of the Spanish WtE plants by Autonomous Communities, 2012

AACC	No. Facilities	Capacity		Power generated (kWh/year)
		No. Furnaces	Nominal capacity (metric tons/year)	
A.C. Balearic Islands	1	4	732,000	[a]245,680,000
A.C. Cantabria	1	1	96,000	84,564,785
A.C. Catalonia	4	9	690,620	288,525,500
A.C. Galicia	1	2	533,742	344,096,500
A.C. Madrid	1	3	300,000	183,641,240
A.C. Basque Country	1	1	245,910	727,000,000
Autonomous City of Melilla	1	1	36,000	3,212,080
Total Spain	10	21	2,634,272	1,631,040,105

Source MAGRAMA; [a]AEVERSU

administrative register of the special regime of electricity production facilities, which is published on the website of the Spanish Ministry of Industry, Tourism and Trade, except for the plant in the Autonomous Community of the Basque Country (Zabalgarbi, S.A., in Bilbao).

At the European Union level, there are about 450 WtE plants with an annual processing capacity of about 78 million metric tons (CEWEP 2014), and so the Spanish plants, with 2.6 million metric tons, would represent around 2% of the total treatment capacity of the European plants.

As shown in Table 3, the Spanish WtE facilities are conventional incineration/combustion plants. Their normal processing capacities range between 3 and 50 metric tons/hour per line, and they can treat waste with an LHV of between 1400 and 4500 kcal/kg without the addition of auxiliary fuel (Muruais and Maíllo 2010).

According to Wilson et al. (2013), in terms of efficiency of conversion into electricity, between 0.4 and 0.7 MWh of electrical energy can be generated with 1 metric ton of MSW through incineration. On analyzing the data about electricity production and the amount of MSW treated shown in Table 3, most of the conversion factors are within that range. Note the case of the Zabalgarbi Plant, which reflects some high values due to its particular conditions. In addition, the Plant in Melilla has a coefficient well below the expected range. Furthermore, no significant difference is observed between the values of plants using grate furnaces and fluidized bed, although it is noteworthy that the latter values are near the upper limit of the range.

All plants began operating before December 2008, so the value of energy efficiency under the premises of the R1 Formula should be at least 0.60. Data are only available for two of them and are very close to the limit set by the Waste Framework Directive, which confirms the difficulty these plants face in attempting to achieve the specific thresholds.

In turn, it can be seen that the choice of grate furnaces is the most widespread. With this system no previous selection or pre-crushing process is required and it can

Table 3 Characteristics of the WtE plants in Spain, 2012

Facility	Type waste	Incineration capacity (metric tons/hour)	Quantity waste treated (metric tons/year)	Electrical production (MWh)	Conversion ratio from MSW to electricity (MWh/metric ton)	Type of furnace	EE-R1[e]
Mallorca-Tirme (Balearic Islands)	MSW	45.75	511,999	245,680	0.48	Roller grate/moving-water-cooled	–
Meruelo (Cantabria)	RDF	11	112,500	85,500	0.76	Roller grate	–
Girona-Trargisa (Catalonia)[c]	MSW	4	–	–	–	Martin grate	–
Sant Adriá del Besós-Tersa (Catalonia)[b]	Rejects and unusable waste (70/30)	40	287,057	135,729	0.47	Sliding grate (Von-Roll)	0.627
Mataró-TRM (Catalonia)	RDF	18	190,000	115,000	0.61	Moving sliding grate (Martin) (2 furnaces)	–
Tarragona-Sirusa (Catalonia)	RDF	15.5	140,000	53,000	0.38	Roller grate	–
La Coruña-Sogama (Galicia)	RDF	47	555,440	342,486	0.61	Circulating fluidized bed	–
Madrid-Tirmadrid (Madrid)[a]	Rejects and unusable waste	37.5	265,919	183,642	0.69	Sand bubbling fluidized bed (3 furnaces)	–
Bilbao-Zabalgarbi (Basque Country)	MSW	30	224,792	658,000	2.9	Sliding grate (Martin)	0.61
Melilla-Remesa (Melilla)	Mass MSW	5	39,302	8446[d]	0.22	Cloves grate (Von-Roll)	–

Source AEVERSU, [a]Madrid City Council
[b]TERSA
[c]Girona-Trargisa data are not available
[d]Equivalent data, since only 2275 MWh were generated owing to a turbine fault during 8 months
[e]Data values published on the website of the WtE plants. The rest of the values are not available

accommodate wide variations in composition and calorific value of the MSW. Only two facilities have chosen the fluidized bed technology, since it has maintenance and capital costs that are lower than those using grate furnaces. They also provide greater overall thermal efficiency and can run on a wide range of solid and liquid fuels. However, it is necessary to monitor the size and the composition of the waste, which generally requires a pre-treatment (Arena et al. 2011).

Besides these two types of incineration technologies, there are also others that are used depending mainly on the type of waste to be valorized (Table 4). Moreover, there are other thermal valorization processes, such as pyrolysis, gasification or plasma, which, although capable of generating good theoretical data regarding energy efficiency, cannot yet be considered as mature in their application to MSW as incineration.

In order to check whether electricity production is a linear function of the amount of MSW treated in the existing plants, the possible correlation between the total amount of MSW treated and the electricity generated within the range of 38,000 and 600,000 metric tons was analyzed. Excluding data on electricity generated by Zabalgarbi, due to the uniqueness of this plant, the bivariate analysis revealed a fairly strong positive linear correlation between the two variables ($R^2 = 0.9282$) (Fig. 3).

Furthermore, using data on the electricity production and total amount of MSW treated by the 10 WtE plants enabled to determine the average production of electricity per metric ton valorized in 2012, obtaining a value of 785 kWh/metric ton. If valorized with this type of plant, the total amount of reject material generated during that year (7.8 million metric tons), could generate around 6,103,046 MWh of electricity. Given that the average electricity consumption per household (≈3 people) is 3487 kWh per year (IDEA 2013), the demand for 1,750,228 households

Table 4 Comparison of the technologies used for incineration

Type of waste	Furnaces type			
	Grate	Fluidized bed	Rotatory	Liquid injection
Granular, homogeneous	Appropriate	Appropriate	Appropriate	–
Irregular	Very appropriate	–	Appropriate	–
Low melting solids	–	Appropriate	Appropriate	–
Organic with melting ashes	Very appropriate	–	Appropriate	–
Voluminous bulk waste	–	–	Very appropriate	–
Organic fumes	Appropriate	Appropriate	Very appropriate	Appropriate
Organic liquids	–	–	Appropriate	Very appropriate
Halogenated sludge	–	–	Appropriate	Appropriate
Organic muds	–	Appropriate	Appropriate	–

Source Prepared by the authors, Centro de Tecnologías Limpias (CTL)

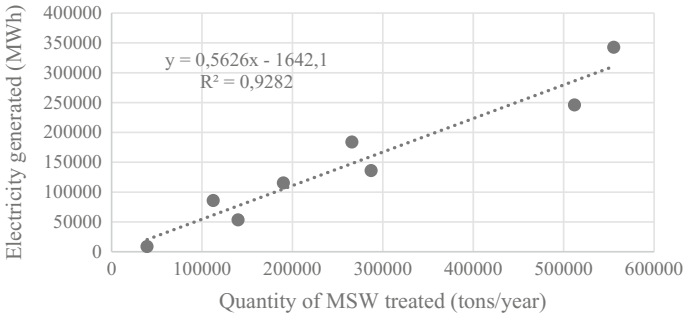


Fig. 3 Correlation between electricity generated and amount of MSW treated by WtE plants, 2012. *Note* No data are available for the Girona-Trargisa Plant

or, to state it in other terms, 5,250,684 people, could be satisfied. In addition, the amount of electrical energy produced per unit of energy contained in the MSW has been determined. Thus, for each kWh of energy contained in the rejects, 0.25972 kWh of electricity are obtained in the existing plants. This is calculated taking into account the average LHV of the reject materials estimated by Grau and Farré (2011).

In the event that all the rejects were transformed into SRF (with an average LHV of 5800 kcal/kg) and considering the same coefficient of conversion as that of the existing plants, it is estimated that the average electricity production would be 1752 kWh/metric ton. Based on this, 9,807,168 MWh of electricity could be generated, thereby satisfying the electricity demands of 2,812,494 households, which is equivalent to 8,437,483 people.

Finally, the number of plants that would be required to cater for the total amount of reject materials generated in 2012 has been estimated. From the data in Table 2 and assuming a nominal treatment capacity of 100,000 metric tons, the construction of 63 new plants would be necessary.

6 Conclusions

In Spain an energetically useful flow of reject materials from different MSW treatment plants is generated every year and, in accordance with today´s waste management and treatment systems, most of it is deposited in landfills. The largest amount of reject materials is generated in sorting and composting plants.

By processing and transforming reject materials into an SRF, it is possible to obtain a fuel with homogeneous properties and a high calorific value. Their use in WtE plants, according to the R1 Formula of the Waste Framework Directive, would increase energy efficiency, because even though there is an energy expenditure in the processing of SRF, this is not taken into account in the calculation of the R1.

As defined by the R1 Formula, it will be very difficult for the WtE plants in Southern Europe to exceed the minimum values set for energy efficiency, because by producing basically electricity and not taking advantage of the heat that is produced (co-generation), it is very difficult to reach the energy efficiency thresholds set by the Waste Framework Directive. In this study it has only been possible to collect energy efficiency values for two plants, both of which slightly exceeded the defined threshold.

The main technology for energy recovery in Spain is incineration, and more specifically grate furnaces. The amounts treated per year range from 40,000 metric tons at the smallest plant to 555,000 metric tons for the largest, and there is a strong positive linear relationship between the amount of MSW treated and the amount of electricity produced.

In 2012 only 13.57% of the reject materials generated were valorized. If all these materials were used successfully, it is estimated that it could satisfy the electricity demands of more than 5 million people. In the case of transformation into SRF, the number would rise to 8.5 million people. Yet this would require the design and construction of new WtE plants.

Finally, it should be said that in Spain there exists room for potential development in this field, both in the design of alternative fuels and in the design and construction of new WtE to valorize them.

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Review of Options for Solving Problems of Frazil Ice in Industrial Water Intakes

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Resumen Muchos procesos industriales requieren el uso de agua bien para refrigeración o como agua de proceso. En las regiones frías la existencia de hielo es muy común en ríos y lagos durante los inviernos. Aún en tomas submarinas, su presencia se convierte en un problema al aparecer el superenfriamiento, cristales de hielo que se multiplican rápidamente. Éstos se adhieren a las rejillas llegando a taponar los sistemas de conducción que alimentan instalaciones como centrales hidroeléctricas, fábricas o incluso suministros municipales. Este fenómeno se traduce en graves problemas, llegando incluso al cierre de la planta industrial afectada. En este trabajo se realiza una revisión de los principales aspectos de este problema en determinadas industrias, un análisis de causas, de posibles soluciones y de casos de aplicación.

Abstract Most of the major industrial processes require the use of water either for cooling or as process water. In cold regions the existence of ice is very common in rivers and lakes during the winter. Even with underwater intakes their presence becomes a problem when supercooling appears. Frazil ice grows rapidly and adhere to the grids coming to clog the pipe systems that feed facilities such as hydroelectric power plants, factories or even municipal supplies. This phenomenon leads to severe problems, even resulting in the closure of the plant affected. This paper presents a review on the main aspects of this problem in certain industries and an analysis of its causes and possible solutions as well as an analysis of use cases.

Palabras clave supercongelación · tomas de agua · procesos industriales

Keywords Frazil ice · Water intakes · Industrial processes

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1 Introduction

In the coldest regions, which suffer from harsh cold winters, it is quite common for the rivers and lakes to freeze, not only at surface level but also deep below, where even frazil ice can easily appear. As a consequence of this phenomenon, the water intakes from different industrial installations (hydroelectric power plants, factories or even municipal supplies) may be affected. In some of the cases it means just a temporary nuisance, whereas in some others the freezing of these water intakes might have catastrophic consequences, as for instance the closure of a nuclear plant (Richard and Morse 2008).

This phenomenon has been happening for many years; in fact, it is known since the very moment the industrial and municipal water intakes were installed in rivers and lakes (Kempema and Ettema 2013). For instance, in 1914 the whole city of St. Petersburg was affected by a water supply cut off as a result of the obstruction of the pipe systems by frazil ice. Therefore, this is a serious issue which requires efficient solutions. However, to this day there are still no definitive solutions to this problem, apart from corrective and preventive actions to be taken in those areas prone to suffer from these setbacks in the winter season.

The problem lies not so much on the appearance of frazil ice but on the way it generates and accumulates. That is, the obstruction of water intake is generated when certain conditions in the environment encourage the formation of highly adherent tiny ice crystals, which adhere to the grids or racks of those water intakes. The rapid growth of these ice crystals irretrievably leads to the complete encapsulation of the water intake duct. This creates a physical barrier to the incoming water, therefore, if this were the case of a nuclear plant, it would run out of cooling water, so it would cease to operate.

The processes of generation and accumulation of frazil ice occur when the intake water temperature descends below the freezing point (supercooling water). This phenomenon occurs when the body of water suffers from a serious heat loss. It is then when tiny ice crystals or ice sheets appear and adhere to any object they get contact with, which has a negative temperature. Another aspect which aggravates the problem is the fact that the water pipelines have a limited access and suffer from pressure changes, which initiate the obstruction process (Ettema et al. 2009).

2 Object

This document addresses a review of the main aspects concerning the formation of frazil ice in industrial environments, including the analysis of the causes, possible solutions and use cases.

Therefore, the suitable environmental conditions for the formation of ice crystals and their growth in cold climates will be analysed. This document will also review the different detection instruments available to solve the problem of ice crystal formation.

Thus, the goal of this research is to offer a compilation on the different solutions available in the market with the aim of using it as background information for the study of specific cases. This should therefore allow the designing of an effective solution for a particular installation, knowing its details and operation conditions.

3 Description of the Issue

Transport systems in northern latitudes suffer from ice clogging as a consequence of the adhesion of active tiny crystals to the underwater structures, which undergo a developing process that eventually will end up clogging the water intake completely. This process may be accelerated by the heat loss caused by the blockage. Once the structure is clogged, it is extremely complicated to unblock it, since the ice will not break even though the surrounding water is not super cooled. It is then necessary either to break the ice using a machine or to melt the ice.

3.1 Ice Crystal Formation

The formation of frazil ice occurs in those turbulent stretches of lakes and rivers which withstand negative temperatures and which also lack the presence of an ice layer to serve as a thermal insulator. This produces a heat transfer from the body of water to the atmosphere and the beginning of the formation of ice crystals (Kempema et al. 2011). Once they are formed, these crystals will tend to adhere to one another as well as to the materials at the bottom of the lake or river; this is a consequence of the appearance of surrounding super cooled water.

There is no definite agreement on the size of the ice crystals that are formed in the water, and are responsible for the clogging of the water intakes; nevertheless, most of the reports and articles recently published conclude that the diameter of these crystals is between 0.1 and 1 mm and that they could reach up to 1 cm (Richard and Morse 2008). Once these particles are formed in super cooled water, they stick to one another forming floccules that rise to the surface or even accumulate in underwater objects (Beltaos et al. 2011).

One of the problems associated with transport systems and frazil ice in water intakes deals with the accumulation of particles into their grids.

The water intakes have grids that serve as filters preventing litter or debris from entering the pipelines. The active ice particles adhere to these structures, rapidly forming bridges, which favors an exponential growth of the ice clogging. As a consequence, a stronger pumping effort is required until, eventually, frazil ice provokes the complete blockade of the intake and makes it impossible to supply more water (Ashton 2011; Kempema and Ettema 2013; Daly and Rand 1991) (Fig. 1).

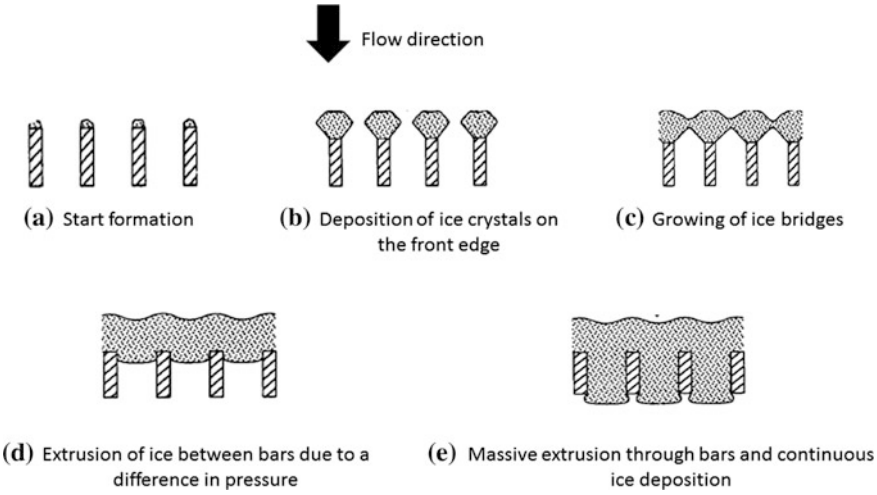

Fig. 1 Pattern of accumulation of frazil ice in water intakes grids (Daly and Rand 1991)

3.2 Influence Factors

There is a series of conditions which are required for the formation of crystals as, for instance, the absence of solar radiation that supplies heat to the body of water, a heat loss due to longwave radiation, evaporation and the lack of an ice layer on the surface (Daly 1994). Besides, the formation of ice crystals is usually linked to open bodies of water and clear nights (Ettema et al. 2009). The amount of frazil ice shall be proportional to the rate and duration of the heat transfers to the atmosphere the water is exposed to Ashton (2011).

Under favorable conditions, once the crystals are formed they continue growing in size as they stick to one another. However, if the turbulence increased, the crystals would start breaking until they end suspended in water.

Thus, the speed acts as a decisive factor in such a way that an increase in speed in the turbulence would reduce the formation of ice crystals. Nevertheless, in those areas of the canals and pipelines where constrictions appear, the speed would be reduced to values below 0.3 m/s, the same as the turbulence. This would imply an accumulation of the ice floccules that could form a continuous ice layer. The speed would increase again after passing the pipe elbow, and the ice particles would be carried downstream under the layer, to which they can adhere to form a "dam" which blocks the water course completely, creating a risk of flooding.

However, the main factor to consider is the decrease of the freezing point when the pressure is increased. A variation in the pressure can recede or accelerate freezing, as well as reconstruct ice chips which pass through the pipelines with pressurized water. The conclusions in Ettema et al. (2009) state that an increase

in pressure of approximately 1 MPa can decrease the water freezing point by 0.074 °C. Within covered conduits, associated with hydraulic valves, pumps, siphons and tunnels, the appearance of pressure changes between 0 and 2 MPa is most usual. Besides, one has to bear in mind that a difference of 100 m in height in the pipelines, will produce a difference in pressure of approximately 1 MPa.

Another point of interest is to know if the frazil ice present in the water is in active or passive status. It is understood that ice crystals are active when they experiment a major heat loss from the water to the cold air, and when there is not an ice layer thick enough to prevent this heat loss. During the cold winter nights, with temperatures below 6 °C, low humidity in the environment and wind, the surface water gets super cooled and as a consequence, generates a certain turbulence in the body of water that cools the water column below the freezing point, which encourages the appearance of ice crystals. The ice particles which are suspended start multiplying and adhering to any object with a lower temperature they encounter. They are then known as active ice particles (Kempema et al. 2011).

On the other hand, there are other suspended ice particles which are considered to be in a passive status. This is because the high content of ice in the surface favors the formation of that insulating layer which modifies the water thermal conditions and the temperature exchange with the atmosphere, generating the inactivation of the ice particles. That is, these crystals lose their capacity to adhere to objects and to one another (Ashton 2011). Therefore, in a passive status these crystals do not cause as much damage as in an active status, since they can be carried away by water without adhering to any structure. Nevertheless, they are still a matter of concern, since in those points of the water flow where the pressure is reduced, they can be activated again provided that the water is super cooled, being able to adhere to the structure itself (Ettema et al. 2009).

4 Ice Crystals Effect in Water Transportation Systems

Water transportation systems are open water pipelines joined to pressurized ducts as, for instance, pump lines, valves, siphons and tunnels, which carry water through the site. These systems usually have variations in pressure and, as a consequence, the water freezing point may be altered.

4.1 Hydropower Turbines and Suction Pipes

As the water flows through the turbine, the pressure decreases dramatically, increasing the freezing temperature of the water flow coming from the turbine. The combination of super cooled water and suspended ice particles is unstable since, occasionally, water absorbs the latent heat from the melting ice and increases the

new freezing point. The new ice crystals suspended in super cooled water may either stick to each other and adhere to the turbine components or else be washed away downstream. If the concentration thereof is high and, at the same time, the water flow is small, the ice will accumulate in the turbine and may even block the passage of water through the turbine.

The length and slope of a penstock plays an important role with respect to cooling. For a given fall, the inclination determines a greater or lesser length, influencing the water transport time during which it can be super cooled. Therefore, for the same conditions, an increased length in the channel produces more frazil ice.

4.2 Pump Lines

As the water flows through a pump, the pressure increases rapidly in the head but it is reduced along the water flow. The freezing point drops as the hydraulic gradient increases in the pipeline, and it may melt the existing ice. The overcooling of the body of water depends on the time there is to cool such water. As the hydraulic gradient decreases, the chances of ice crystals formation increase if the water is super cooled. The amount of crystals formed is the same as the melted ice and dependent on the loss of heat through the walls of the pipeline. When water is super cooled, the crystals are activated and can agglomerate into pieces, floccules or sleet and they can adhere to the pipes. This would generate an increase in the pump resistance, however, the heat emitted by the pump would be able to reduce the concentration of ice.

4.3 Siphons

It is common to find inverted u-shaped siphons in mountainous terrains. The changes in pressure resulting from this shape is what generates the different freezing points in small discharge lines. As water flows through the siphon, part of the crystals that may exist are deposited after passing the first elbow, at which point both speed and pressure decrease, which favours the formation and deposition of crystals. Therefore, the longer the lower section is, the higher the possibility of clogging by ice crystals, which increases the resistance to the water flow.

Clogging by frazil ice is most likely to occur when there is an ice concentration just below the required level. Therefore, water reaches its freezing point but without being frozen. It is just in that moment when the ice begins to melt due to the pressure conditions and the water continues to cool until it reaches supercool temperatures. Then, the ice crystal formations appear once again, and they can adhere to the entire structure, blocking it completely.

4.4 Diversion Tunnels

Inside the tunnels there is not the same increase in pressure as inside pipes or siphons. In most tunnels, water experience a relatively modest pressure drop, unless they are tunnels with fully vertical falls. Furthermore, the temperature of the pipe walls, if it reaches its maximum capacity, can exceed freezing temperatures and heat the water flows. However, tunnels can also suffer from major problems as, for instance, the blocking of grids, accumulation of drifting ice chunks and accumulation of crystals formed by the turbulence of the flow at the water inlet.

5 Detection Instruments

The problem of ice clogging occurs at a water temperature of −2 °C under suitable weather conditions, that is, on clear nights, under very low temperature conditions and ebb tide. Otherwise, the water would have to be at a much colder temperature, around −14 °C. However, once the ice crystals are formed, they can remain active for a longer or shorter period of time, depending on the surrounding conditions. For instance, when the tide rises it brings "warm" (0° C or higher) water currents, allowing the ice particles to become deactivated or even to melt (Richard and Morse 2008). However, in Richard et al. (2009) it was concluded that the determining factor is the concentration of crystals suspended in water, while the water temperature and other environmental conditions are considered as less relevant.

Therefore, an effective detection of frazil ice formation as well as its distinctive features, will help to decide which methods are the most adequate to apply. According to Marko and Jasek (2008), the most important factors that affect ice formation during freezing periods are the air temperature and the flow speed. The heat transfer from the surface water to the atmosphere is the main cause of a decrease in water temperature and it is also dependent on the shortwave and longwave radiations, on evaporation or condensation and on convection and precipitation. Therefore, the rate of heat transfer by area can be calculated according to meteorological and hydrothermal principles. Thus, it can be concluded that it is possible to predict the water temperature and, therefore, the upcoming formation of frazil ice, knowing the rate of heat loss and the hydraulic currents (ambient temperatures around 0).

For instance, in Giffen (1973), an electric power system controls the water temperature using a sensor. Once it detects the required water conditions for the formation of ice crystals, it warns the operator to activate the heating system of the water intake grid.

5.1 Sonar

Evidence suggests that it is possible to detect and quantify the presence of ice crystals as well as their sensitivity to environmental factors using acoustic signals. This technique was originally used for the detection of sea ice chunks. There are different options of this technique. SWIPS (Shallow Water Ice Profiler Sonar) is a program for monitoring ice in shallow waters. The changes in acoustic frequency help distinguish the active from the inactive crystals. In addition, the great advantage of this device is that it keeps the components completely isolated and sheltered in a place near the coast, where all the data collected will be safely stored (Marko and Jasek 2008).

Another version of this form of detection is the Upward looking Ice Profiling Sonar (IPS4). Its special feature is the ability to record vertical profiles of acoustic echo. A third option would be the Broadband Acoustic Doppler Current Profiler (ADCP), which measures current profiles. In order to obtain acoustic and optical images in real time, it is necessary to use a Remote Operate Vehicle equipped with powerful lights, a camera and a high definition image sonar (Richard et al. 2009). Another prototype is the Swallow Water Ice Profiling Sonar (SWIPS), developed by ASL Environmental Sciences to measure the properties of ice in rivers. It is implemented on the riverbed, from where acoustic signals are transmitted to the water column. The intensity of the reflected signal is related to the size and number of items present in the water (Riyadh et al. 2010).

5.2 Laser Doppler Velocimeter (LDV)

It uses an optical system that works with specially designed electronic circuits. It continuously records the number of pulses produced by the presence of ice crystal particles in the area of sensitivity per time unit and the speed detection circuit determines the flow speed. These two measurements allow a constant calibration to determine the concentration of ice crystals.

5.3 Remote Detection of Ice Movement

The slow-moving sections of rivers are controlled by thermal processes where the water undergoes a heat transfer to the atmosphere, which can generate the formation of ice crystals in open supercooled waters. Therefore, it is highly important to know when the ice layer breaks. The system provides continuous monitoring of the ice

layer and the ice movement in the river (US Army Corps of Engineers 2000). It consists of a pair of sensors anchored to the ice cover and connected to a voltage source capable of reading the return voltage. This system is connected to a satellite data collection platform located in a USGS (United States Geological Survey) meter that transmits data every 4 h.

5.4 Others

There are sets of devices installed on steel platforms which are also used for the monitoring of the conditions for ice formation. These devices allow a more comprehensive data collection. Together with the described sonars and LDV, there are sensors such as the Optical Backscatter Sensor (OBS 3) which measures the suspended solids and the turbidity of the water column using optical backscatter methods. They also include thermocouples, of which the THX-400 NPT is the most accurate, weather stations and cameras (Richard and Morse 2008).

On the other hand, there are several detection instruments developed in the 90s that are generally quite simple and inexpensive. For instance, an underwater frazil ice detector, which is placed in the pipeline as if it were a grid of the water intake. As ice crystals start appearing, the pressure of flow rate changes and, when this change in pressure is detected, the alarm system is activated (Daly and Rand 1991). There is a similar method that detects ice growth by placing a parallel plate capacitor submerged near the water intake, so that the water entering the intake is in contact with the plates. If there were ice crystals in the water, they would stick to the plates, accumulating and generating changes in capacitance. The difference between the dielectric constant of ice and water and the change in electric capacitance between plates would therefore indicate the presence of ice crystals. Upon detection of ice in real time, the alarm system would be triggered (Yankielun 1999a). There is another method of detecting ice crystals adhered to the submerged grid. It consists of a casing located below water surface and close to the grid of a water intake. It comprises a pair of parallel conducting bars situated close to the casing. These bars are in communication with an electromagnetic wave generator inside the casing. A coaxial transmission line is connected from the casing to the bars. In addition, there is also a monitoring station receiving signals from the bars. The wave generator propagates electromagnetic waves to the bars to continue their travel forth and back; calculating the length of travels back and forth, it can determine the amount of ice deposited on the bars (Yankielun 1999b).

6 Alternatives for the Removal of Frazil Ice

The different options available for the control of frazil ice are divided into two large groups: proactive and reactive.

6.1 Proactive Measures

The proactive control measures refer to those that prevent the formation of frazil ice in the water intakes. For instance, as previously mentioned, the thick layer of ice that is formed on the surface of the body of water shall act as a thermal insulator to maintain a proper water temperature that does not allow crystal formation. Therefore, a proactive measure could be to favour the formation of this thick ice layer. The mechanical control is then focused on the retention of ice, creating a permanent ice cover, or on the retention of moving ice in a given location.

These measures include stabilizing freeze without restricting water flow. They include, for instance, the installation of dams, artificial islands, cribs, piers, dolphins (rigid or semi-rigid structures) and ice booms (flexible structures); the installation of water jets to dissolve any accumulation that might occur and the use of a hand rake to remove ice accumulation.

Of all these measures, the "ice booms" are especially remarkable for being the most cost-effective solution while still being reasonably efficient. These are barriers anchored by a chain and a floating cable. They are used to encourage the formation of an ice cover near the surface of the water intakes, but they can also be used as a protection barrier, to prevent floating debris and garbage from entering the water intakes. They are usually made of different materials such as wood, plastic or steel.

Air bubbles are used to heat the water at a certain depth and melt the ice or, at least, delay its formation. It consists of an air system that releases large amounts of compressed air at a given depth to induce or cause deviating speeds towards the surface. These streams of bubbles avoid or at least deflect the ice and debris away from the area. They can be installed occasionally for a given location or linearly in order to form a barrier.

In addition, the adhesion of ice can be prevented or at least reduced by using equipment specially designed for this purpose such as, for example, the bars from the grids of water intakes which favour a laminar flow and decrease the possibility of obstruction, so as not to contribute to the accumulation of ice at the front of the bars. These grids can be made of composite materials or PVC with low thermal conductivity, together with certain characteristics of surface roughness.

Finally, there is the option of anti-ice coatings that have been formulated to reduce the adhesion of ice to the treated surface. A research conducted by the US Army Cold Regions Research and Engineering Laboratory shows how some of these coatings allow up to two thirds less adhesion (US Army Corps of Engineers 2002). Furthermore, some coatings such as silicone polyurea and polyurea are also recommended to prevent the adhesion of zebra mussels. Therefore, these coatings will be an aid to slow down the clogging by ice crystals, however they cannot prevent it just by themselves.

6.2 Reactive Measures

Reactive measures are those actions performed in order to prevent ice from growing once the ice crystals are already deposited on the surface of the installation.

Mechanical rakes are widely used to remove ice crystals adhered to the bars of the grids located at the entrance of the water intakes.

Thermal control measures are also an option for controlling the accumulation of frazil ice. This method uses heat to maintain the ice formation below a certain thickness. On the other hand, the recirculating water system is one of the most used in the industry. It consists of recirculating heated water during cooling operations. This water is then discharged through the outfall.

There is also the option of heating the bars of the grid to prevent frazil ice adhesion. The bars should be maintained at a temperature of, at least, 0.1 °C. However, the temperature should be kept at 1.0–1.5 °C in those periods of high concentration of ice crystals. To provide this heat, hollow bars must be designed, which allow the flow of hot water inside (US Army Corps of Engineers 2002).

Other facilities have installed back flushing or backwash pressure systems. The pressurized water is released from the rear of the intake grid in order to remove the particles of ice adhered to the outer face. In fact, these ice cleaning systems can be part of the structure of the intake grid. Johnson Screens has developed cleaning systems for water intakes to remove debris stuck in the intake grid by pumping liquid inside the grid using nozzles. This system also incorporates the heating of the liquid to remove or prevent the formation of ice on the grid (Ekholm and Dilipkumar 2013).

Another option is to apply an electrolytic treatment. It involves the application of continuous low currents to melt the ice by electrolytic decomposition. An electro-expulsive de-icing system can also be applied by electric current pulses flowing in opposite directions (US Army Corps of Engineers 2000). This latter technology has been developed for avionic systems; however, its application for issues concerning frazil ice is still under research (Table 1).

Table 1 Summary of the different measures

Type	Technology	Advantages	Disadvantages
Proactive	Ice booms	Low cost. Help control ice cover. Mostly used in the Great Lakes. No charge loss. Tested at real scale	Absence of ice crystals not guaranteed. Insufficient as a single measure
Proactive	Air bubbles	Allows different bubble configurations and combinations. No charge loss. The use of hot water is permitted to increase efficiency. Tested at real scale	Lack efficiency in troubled waters. The outlets can be frozen for short periods of time during cold winters
Proactive	Specially designed grids	Lower cost than the construction of a new water intake. Reduce maintenance if compared with the traditional ones	Insufficient as a single measure
Both	Backwash gate	It combines the special design of the grids with frost protection. Sinergy for the active removal of debris	New technology. Efficiency unknown
Proactive	Low-tack bars	Reduce the probability and severity of the problems caused by ice crystals	Insufficient as a single measure higher maintenance costs than stainless steel
Proactive	Defrosting covers or paint	Reduce the probability and severity of the problems caused by ice crystals	Insufficient as a single measure. It requires frequent application
Reactive	Power rakes	Efficient. Also used for removing debris. Tested at real scale	Requires investment. Not feasible for hard-to-reach locations. Increase in maintenance cost due to friction
Reactive	Water recirculation	Low operation cost. It reduces costs due to heat discharge. Tested at real scale	High initial investment to implement retrofitting. Needs to recirculate large volumes of water to be efficient
Proactive	Heated bar grids	Effective. Tested at real scale	High energy consumption increase in health and safety risks
Reactive	Backwashing	Effective. Tested at real scale	High energy consumption
Reactive	Electrolytic detachment mechanism	Effective	High energy consumption. Technology under development for water intakes
Reactive	Electro-expulsive detachment system	Effective	High energy consumption. Technology under development for water intakes

7 Conclusions

Despite the existence of the frazil ice issue for more than 100 years, there is still no comprehensive and effective solution suitable for all installations. This is mainly due to the fact that the design of the facilities and their water intakes and water systems are unique. In addition, the cryologic, hydrologic and hydraulic processes for each lake and river are also different. Moreover, the ice crystals can appear in different forms, depending on the flow conditions and the weather. Also, even those options that may be effective in some cases and fix the damage caused by ice clogging, are usually very expensive due to operational costs. This would be case of the method of heating the water intakes, which requires high energy consumption.

However, findings have revealed that it is possible to know certain factors such as the design and the environmental conditions that can trigger the development and growth of ice crystals. Therefore, it is crucial to know and understand these factors and their consequences during the design stage. It is also essential to install a combination of preventive and corrective measures that must be suitable and effective according to the configuration of each water intake.

As the ideal situation would be to avoid the formation of frazil ice, the infrastructure should be designed to allow the existence of high pressures and turbulence in a defined range. It would be also interesting to encourage the formation and stabilization of an ice cover using ice booms and other structures that prevent heat loss.

In the event that the ice crystals have already appeared, it is essential to prevent them from adhering to the infrastructure and prevent its growth, as well as to prevent a temporary blockage. It is advisable to have a proper separation of bars in the water intake grids, to have vee-wire welds and apply certain special coatings that repel ice crystals.

In addition, the installation of ice detection instruments is recommended to start the reactive mechanisms such as bubbling air, water discharges and thermal control systems along with mechanical brushes to remove the ice once it is already adhered.

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Environmental Behaviour of an Element of the Construction Sector

Maria Luz Garcia Ceballos, José Ramón de Andres Diaz and Francisco Pinto Oliver

Abstract Most European cities use prefabricated cement-based materials to transform public spaces to be used by citizens. These facilities must be resistant, economic, functional and, above all, sustainable. Furthermore, civil works have a very high consumption level of raw materials and energy, which implies high environmental emissions. Ecodesign is a response to comply with these criteria throughout the lifecycle of a product in order to prevent or reduce its environmental impact. The Life Cycle Analysis (LCA) methodology allows for evaluating all the processes related to a product, to identify key points and to establish a strategy for improvement. The main objective of this work is to show the results of the application of the LCA for the common precast concrete pavers used in civil works, analyzing their entire life cycle: from obtaining the raw materials for their production to the pavers' end of life. The main reason for this LCA is to assess the environmental performance at the various stages of their life cycle and the environmental burdens associated with these stages, so that possible improvements can be identified.

Keywords Ecodesign · LCA · Civil works · Environmental impact

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1 Introduction

Most European cities use prefabricated cement-based materials to urbanize the ground, converting it into public spaces that will be used by citizens. These facilities must be resistant, economic, functional and, most of all, sustainable. Sustainability is a requirement that has become increasingly important over the last years due, not only to economic aspects—mainly cost and maintenance—but also because of the environmental aspect.

The environmental impact caused by human activities should become an additional aspect to be studied in any engineering project. In particular, in the civil work and urbanism sector, which requires a very high consumption level of raw materials and energy—and represents an important percentage of the Spanish Gross Domestic Product—generating high emissions to the environment (Peláez Ramos 2011).

The consideration of environmental criteria in the design phase of a product and/or service is called Ecodesign. Ecodesign is originated as an answer to the need of introducing these criteria throughout the life cycle (LC) of a product. The objective is to prevent and reduce the environmental impact—mainly to minimize waste, emissions and energy costs (ISO. UNE-EN-ISO 14006:2011 2011). Ecodesign is the key element towards sustainability and responsible consumption since it brings new concepts such as the product-system approach and the life cycle, and integrates economic and social aspects like eco-efficiency and sustainable eco-design (IHOBE 2000).

The Life Cycle Analysis (LCA) methodology allows quantifying all the processes related to a product and/or a service from the point of view of the system inputs—raw material and energy—and the outputs—emissions to the ground, sea or air and waste. It identifies the key points and allows to establish an improvement strategy (ISO. UNE-EN-ISO 14040:2006 2006) (Fig. 1).

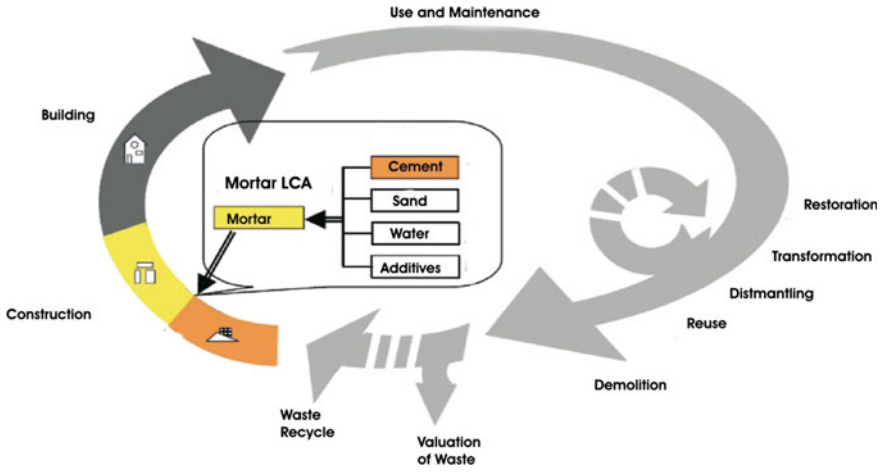

Fig. 1 LC of the cement-based prefabricated elements. *Source* Mora et al. (2008)

2 Objectives

The main objective of this study is the LCA of the precast concrete paver used in civil work and urbanism. Its aim is to analyse the life cycle of the paver from the extraction of the raw materials used to produce it, until the end of its useful life. The paver model under study is the Holanda 6, with dimensions 200 × 100 × 60 mm.

This LCA intends to assess the environmental behaviour of the different stages of its life cycle and the environmental impacts linked to these stages, and to identify possible improvements.

It also intends to develop an inventory of materials and processes for each stage of the LC, to carry out the LCA.

Because the paver is a pavement element, it is located in level 2 (see Fig. 2). The environmental impacts of this level are classified according to the life cycle stage:

- Raw material extraction, manufacturing and installation:
  - Consumption of energy and natural resources in the extraction processes of raw materials, manufacturing, installation and transport.
  - Noise and vibration production.
  - Waste production due to excess materials in processes and packaging.
  - Emission of particles to the air (e.g. dust).

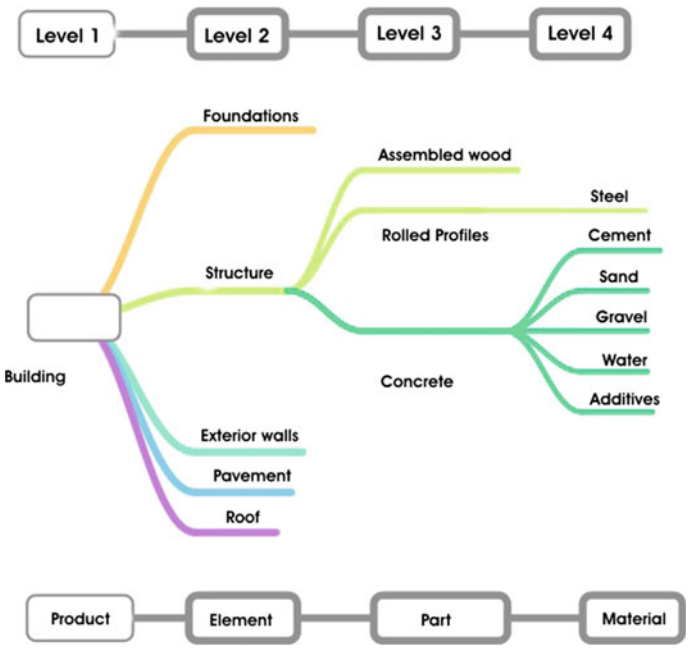

Fig. 2 Levels of the construction products. *Source* Adapted from Carvalho Filho (2001)

- Use and maintenance:
  - Consumption of energy and resources in the maintenance processes.
  - Production of waste and toxic substances according to the maintenance processes, their nature and service life.
- End of life:
  - Consumption of energy and resources in the transport and recycle processes.
  - Production of waste for the non-recycled part.

Therefore, to perform the LCA it is necessary to study:

- The raw materials of the prefabricated cement-based elements (UNE-EN 1338:2004/AC: 2006).
  - Cement, sand, water and additives.
- The installation of paver pavements.
  - Components layers, determination of the standard sections (Fenollar 2011).
- Use and maintenance of paver pavements (Asociación Española para la Investigación y Desarrollo del Adoquín de Hormigón (2004a, b) y Malaka de Prefabricados (2009).
- Paver end of life.
  - Concrete recycling. 95% of the pavers are recovered for recycling (Asociación Española para la Investigación y Desarrollo del Adoquín de Hormigón 2004a, b).

The study is based in the production analysis performed by Malaka de Prefabricados, a company from Malaga created in 1994.

3 Methodology

3.1 Calculation Software

The selected LCA software is SimaPro v7.3.3 from PRé Consultants. The database used is Ecoinvent v2.2.

The calculation has been done by using the spreadsheet Numbers.app from Apple.

3.2 Functional Unit

The functional unit (FU) to be used in this study is 1 m^2 of paver.

The reason behind this decision is that the buying orders as well as the manufacturing batches are managed in area units instead of by the number of paving

blocks. Each manufactured tray consists exactly of 0.5 m^2 of pavers, model "Holanda 6". By establishing 1 m^2 as a functional unit, calculation is simply made for 2 trays.

3.3 System Limits

The system limits define the unitary processes to be included in the system, that is: they determine which unitary processes must be included in the LCA. The system limits selection and the stage exclusion must be coherent with the study objectives (ISO. UNE-EN-ISO 14040:2006 2006):

- No stage has been excluded in the analysis, not even those with little significance.
- The system limits are established by the production process depicted in Fig. 3. Not included inputs and outputs are considered to be out of the analysis.
- All the pavers are considered recyclable, although 5% of them are lost in waste disposal sites mixed with other waste material (Asociación Española para la Investigación y Desarrollo del Adoquín de Hormigón 2004a, b).
- The constituent layers can also be recycled, but they will only be considered for the installation and use of pavers. This is because they can be reused for new installations after a change of the paver layer.
- This project has been conceived for the geographical area of Málaga in the year 2013 and uses data adapted for that scenario. Thus, the electrical mix is updated as of 2013 for Spain (García Ceballos 2013).

3.4 Allocation Procedure

The procedure to allocate future comparative assertions, should they exist, must include all the inputs and outputs produced in each process as well as the ones considered for this project. Omission of stages, processes, inputs/outputs must be avoided, even if they do not significantly modify the final result.

3.5 Selected Impact Categories

The ReCiPe method contains 18 categories for impact category selection. The most significant ones have been selected according to the chosen objectives and the system:

- (CC[HH]). Climate change—human health.
- (HT). Human toxicity.

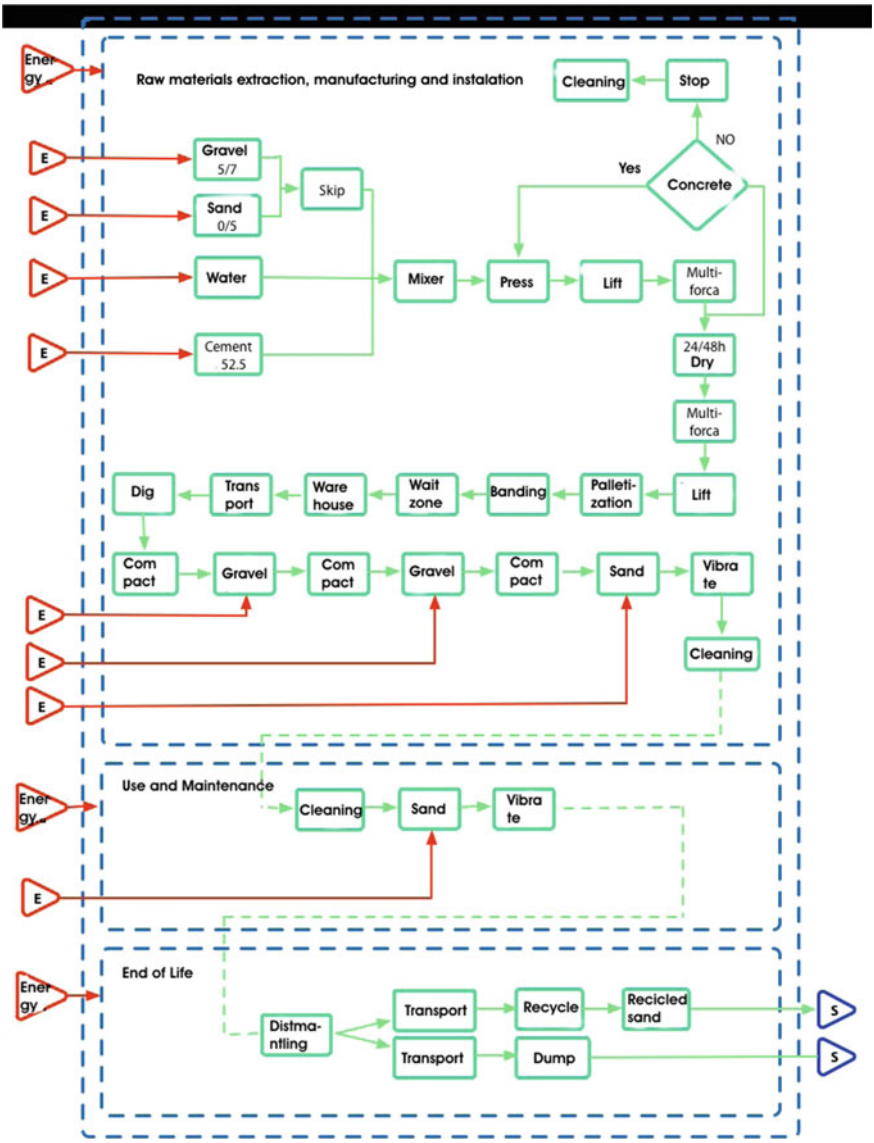

Fig. 3 Scheme of the system flow for paver production. *Source* Prepared by the authors

- (PMF). Particles formation.
- (CC[Ec]). Climate change—ecosystems.
- (ALO). Agricultural land occupation.
- (NLT). Natural Land Transformation.
- (FD). Fossil resources depletion.

3.6 Hypothesis

UNE-EN-ISO 14044 Standard indicates that "initial hypothesis and selection criteria should be clearly defined for entries and outputs upon which the cutting criteria are stablished":

- The distance from the raw materials to the factory is 8 km for aggregates and sand (from Alhaurín de la Torre) and 30 km for cement (Málaga—El Palo). The raw materials are not always coming from the same place.
- A 16-32-ton truck has been considered for the transport stage, only one-way. It meets the EURO 4 emissions criteria.
- The factory has a service life of 15 years.
- It is assumed than main streets are paved, with C1 traffic category and the esplanade quality is E2 with a granular base.
- Paver pavement will be sealed with sand. Cement sealers will be avoided for easer maintenance and recovery.
- Sand losses between maintenance periods are estimated in 50%. Maintenance is estimated to be performed every 5 years, to comply with regulation (Asociación Española para la Investigación y Desarrollo del Adoquín de Hormigón 2004a, b).
- The distance between the pavers dismantling place and the waste disposal site or recycle plant is estimated to be 50 km, assuming the facility is located in the Málaga metropolitan area.

3.7 Data Quality Initial Requirements

Data has been gathered during 2013, so calculations may vary when extrapolating to other years. The geographical area considered is Málaga.

Input data has been provided by Malaka de Prefabricados. This is a Company from Málaga that manufactures pavers since 1994. Figure 3 shows inputs, outputs and the different stages of the manufacturing process.

4 Results and Discussion

4.1 Full Life Cycle Environmental Impact Evaluation

After studying the different life cycle stages, a full analysis of the product will be conducted.

The obtained results show that the use, maintenance and end of life stages have less impact than raw material extraction, manufacturing and installation.

Figure 4 shows all categories of impact analysis. Each of the categories are measured in different units, so they are presented with a percentage scale.

To detect the relevant impacts, a normalized representation has been used.

Figure 5 shows relevant impact categories at this stage.

Fossil resources depleting is the category with the highest impact. The outstanding stages are raw material extraction, manufacturing and installation for all impact categories.

Balanced data of Table 1 shows results similar to normalization.

In this option, points are assigned to classify the different categories. All impact categories are represented using the same unit, the point (Point, Pt)[1] (IHOBE 2009). The higher the Pt number, the greater the environmental burden.

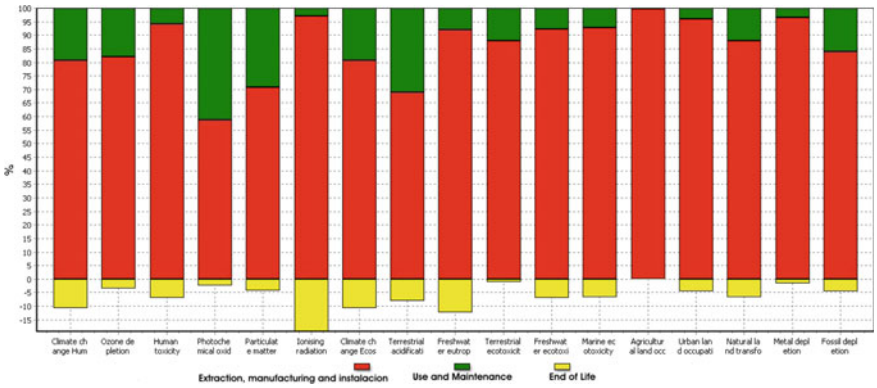

Fig. 4 Impact quantification for the entire LC. *Source* Prepared by the authors

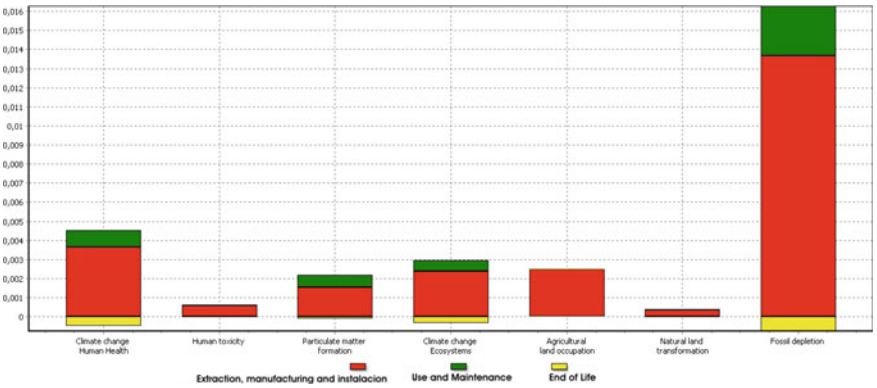

Fig. 5 Quantified normalized impact for the entire LC. *Source* Prepared by the authors

Table 1 Balanced impact categories

Balanced impact categories							
Process	CC[HH] (%)	HT (%)	PMF (%)	CC[Ec] (%)	ALO (%)	NLT (%)	FD (%)
Extract., manuf. and inst.	90.4	101	74	90.4	100	94.4	88
Use and mainten.	21.6	6.46	30.5	21.6	0.14	12.8	16.8
End of life	−12	−7.45	−4.56	−12	−0.09	−7.21	−4.85

Source Prepared by the authors

It can be concluded that the stage with the highest contribution to the paver environmental profile is the raw material extraction, manufacturing and installation stage. The usage and maintenance stage contribution is high enough to be disregarded. Finally, the end of life stage has a minimal contribution, but it has to be taken into account to comply with the 1999/31/CE European directive about waste disposal.

4.2 Interpretation

The paver LCA indicates that the stage that has the greatest influence in the environmental profile (using ReCiPe method), highest energy consumption (Cumulated energy demand method) and highest CO_2 equivalent emission (IPCC method), is the raw material extraction, manufacturing and installation stage.

5 Conclusions

In this study, an LCA has been performed for a precast concrete paver with dimensions 200 × 100 × 60 mm, taking 1 square meter of it as a functional unit.

The LCA is a powerful tool to detect which processes have the greatest environmental impacts and to evaluate these impacts in a normalized and objective manner. Once these hot spots have been detected, the company can be informed, so that some process improvements can be undertaken. This will improve the economy, energy consumption, and can be used as environmental advertisement. It is also possible to use this type of studies to establish an environmental label (ISO. UNE-EN-ISO 14020:2002 2002) to stimulate the demand of products and services with less environmental impact, which include relevant information about their life cycle—for instance, consumed energy or generated CO_2 equivalent. This will satisfy the increasing demand of products with environmental information.

The greatest environmental burden is achieved at the raw material extraction, manufacturing and installation stage. The usage and maintenance stage has a lower impact (though not negligible) and end of life stage has been considered due to its environmental benefits.

The unitary processes with highest environmental burdens are raw materials for the bituminous layer, coarse aggregate used in the installation base layer, and the manufacturing process of the Portland cement.

The inventory of materials and processes has been the most complex part of the work. This is because most of the processes were not included in the Ecoinvent database and there was very little information available. The lack of information about other studies which used the LCA as an assessment method for this sector has been another source of complexity for this work.

The analysis software, SimaPro, has greatly simplified the Evaluation of the Life Cycle Inventory and the Interpretation stages, not only because it incorporates the ReCiPe method, but also due to its adaptation of the work flow to the UNE-EN-ISO 14040:2006 (2006) normative.

The analysis method used in this study can be applied not only to pavers, but also to any other construction product or service. So it can be used as a base to establish comparisons between other cement precast products, or different pavements, such as asphalt or ceramic pavements.

It would be interesting to extend this study to other countries, with different electric mixes or different manufacturing processes.

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Identification and Measurement of Complementarity Variables in Strategic Projects of Water Irrigation from the Sustainability Practices. Case: Republic of Ecuador

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Abstract Based on the assessment of water resources in Ecuador and strategic water projects in this country, questions were raised about the need to complement these projects under the sustainability approach, effectively balancing the original intentions, needs and environments with the services currently offered. To do so, 32 variables of complementarity were identified and characterized: 7 economic variables, 11 environmental variables and 14 social variables. These variables were used to perform an expert panel assessment of 16 strategic projects from the irrigation water sector in Ecuador. Experts assessed the current implementation of such practices, the performance level achieved and their relative importance. The results

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allow to identify, assess and prioritize gaps in such projects, in existing complementarity from the initial planning stages, providing a basis to address these gaps in future projects.

Keywords Sustainability · Complementarity variables · Complementarity gaps · Strategic projects · Irrigation projects

1 Introduction

Those projects, which due to their importance and magnitude have decisive economic, social, political or environmental influence, are identified as strategic projects (also known as flagship projects) within which water projects are included. These projects should be oriented to the full development of rights and social interest. Given their importance, in the Republic of Ecuador they are contained in the Art. 313 of the Constitution of Ecuador (2008). Water projects can also be undertaken for various purposes: drinking water, irrigation, hydropower or multipurpose. This research focuses on water irrigation projects, and for this purpose, 16 projects in the Republic of Ecuador were studied. This work has been possible thanks to the collaboration provided by the Ecuadorian national water authorities.

The projects have a reality in the planning stage and other when they are being developed or after completion; this causes a deficit on the services which are finally offered and a gap between the original intentions and the current needs, generating outbreaks of civil unrest and operating conditions not suitable for their installed capacity. This situations cause gaps of complementarity which can be **Non-constructive or Constructive**.

Non-Constructive gaps are those that emerge when trying to effectively balance the original intentions, current needs and environments with the services offered by the infrastructure finally built, while Constructive gaps are the differences that occur when comparing the planned constructive processes of the project infrastructure with their status during the construction stage, if these gaps do not allow to achieve the constructive objectives of the project. Some examples are: items originally not included in the planning but essential for the completion and operation of the civilian infrastructure, work volumes not included in the original plan, adequacy of materials and technologies used to optimize construction processes and implementation of contingency plans for unforeseen events or force majeure. All these gaps are collected through work orders that after being approved are implemented and become part of the final work of infrastructure. They are included in the final acceptance of the project and, thus, become part of the final budget that generally differs from the originally planned budget.

The aim of this study is the measurement of **Non-Constructive Gaps**. The best sustainability practices of non-constructive variables were chosen to be evaluated in the strategic water irrigation projects, for the economic, environmental and social complementarity characteristics of the built infrastructures (ECLAC 2001).

The measurement and evaluation of the non-observance and/or unfulfillment of these practices or variables will help identify the different types of non-constructive gaps generated in water and irrigation projects, which simultaneously pose risks for the sustainability achievement of the project.

Therefore, the Non-Constructive Variables, hereafter referred as Complementarity Variables, or in other words, the sustainability variables, are the vehicle that allows to calculate the Non-Constructive Complementarity Gaps.

The complementarity variables were obtained from a scientific documentation review containing studies on sustainability indicators, which provided the basis for identifying the best sustainability practices applicable to irrigation projects in the water sector. These were finally validated by industry experts and the opinion of the authors.

1.1 The State of the Art in the Complementarity Variables

A large amount of information was found in the scientific literature reviewed, on the development, generally by the central governments, of scale or national coverage indicators. Moreover, civil society's organizations and sectoral or territorial government departments have been developing sustainability indicators that highlight local (cities), regional (basin, bays), thematic (e.g. biodiversity, water) or sectoral (energy, transport, agriculture) phenomena (ECLAC 2001). Two research projects, were also found, that aim to create a standard for indicator systems used to evaluate sustainability in the construction sector and try to solve the problems posed by the diversity of indicator systems co-existing in this sector. One is the research project LEnSE (Sixth Research Programme of the EU), and the other is supported by the WCCE (World Council of Civil Engineers). States that for more than a decade the concept of sustainable planning, based on the Agenda 21 program, has been applied to urban and building planning. In fact, a significant number of studies have focused their analysis on the environmental and economic dimensions of sustainability; however, there are few studies regarding the social dimension and even less studies applied to the construction sector (Fernández and Rodriguez 2010). Therefore, the term "sustainable construction" was focused almost exclusively on buildings, and gradually, sustainability goals have been introduced in civil engineering projects (Valdes and Klotz 2013). In this new context, sets of sustainability indicators found for civil engineering projects, have been used in bridges and viaducts such as the SUSAIP model (Sustainability Appraisal in Infrastructure Projects) consisting of criteria identified through interviews and surveys to participants in the different stages of the project life cycle (Ugwu et al. 2006); and ETI (Technical Sustainability Index) proposed by Dasgupta and Tam (2005), where indicators have been created based on the existing scientific literature. Sustainability indicators,

mainly related to water irrigation projects, have been reported for hydroelectric projects and are collected in the article Sustainability indicators for run of the river (RoR) hydropower projects in hydro rich regions of India (Kumar and Katoch 2014), including 20 social, 22 environmental and 19 economic indicators, from 22 different scientific articles.

Consequently, given that the construction sector is moving towards an increase and a development of the series and the type of social, economic and environmental indicators (Zhang et al. 2008); and that the development of categories or sets of appropriate indicators for common types of civil infrastructure systems could streamline the sustainability analysis (Dasgupta and Tam 2005), it is important to identify sustainability good practices, specifically for water projects of the irrigation sector that can be used for identification and measurement of a smaller number of indicators for the sustainable management of water irrigation projects. This has to be done from the point of view of binding or third generation indicators, because they represent the most important challenges concerning the state of the art review of environmental sustainability and sustainable development indicators performed by the Division of Environment and Human Settlements, which was published by the United Nations in 2001.

1.2 The Water Basins in the Republic of Ecuador

The water basins of the Republic of Ecuador with abundant renewable water flow from two hydrographical groups: the Pacific and the Amazon. They offer 430.2 km^3/year of available water resources (AWR) and 143.4 km^3/year of usable water resources (UWR), and they do not show signs of shortages at the construction stage of 16 strategic mega projects of the irrigation water sector during the 2012–2017 period. According to a recent research, (a summary is shown in Table 1) only 3.72% of UWR (Gallardo et al. 2014) will be used. On the other hand, the referential investment goals in water megaprojects that the Ecuadorian government is planning to implement through the National Water Secretariat (SENAGUA) in the period 2012–2017, reach 2745.94 million dollars over these two basins. The increase of consumptive and non-consumptive demands that these constructions will generate, raises questions about the need to supplement water projects and efficiently balance the original intentions, needs and current environments, with the finally offered services, with a focus on sustainability and about the inherent risks that need to be identified, monitored, evaluated and mitigated.

These facts allow justifying this study proposal, to potentiate and optimize water projects through the reduction of risks caused by no-constructive gaps before, during and after construction, with a sustainability approach.

Table 1 Criteria for determine water scarcity in Ecuador

Falkenmark (1986)	Availability index	Renewable water resources (which are considered constant over time)/ population	1.000 m^3 and 2.000 m^3/ person/year	Country has water problems (UK, India, Pakistan, and Tanzania)	Ecuador 29.700 m^3/ person/year. No scarcity problems
			Less than 1.000 m^3/ person/year	Country suffers water scarcity	
Otros ONU (1997	Level regulation	Consumption/renewable water reserves in an area in a given year	When the freshwater use exceeds 10% of annual renewable water resources	Country, begins scarcity	Ecuador 143.4 km^3 UWR used/year, will use 3717% no scarcity problems
			When over 20% of annual renewable water resources	Country with pronounced sca rcity	

Source Falkenmark (1986), ONU/United Nations, Department for Policy Coordination and Sustainable Development (DPCSD) (1997)
Elaboration Prepared by the authors

2 Objectives

Research general purpose:

Identify, characterize, measure and prioritize the complementarity variables in strategic irrigation projects, through the case study of the strategic water irrigation projects in the Republic of Ecuador.

Specific research objectives:

SPECIFIC OBJECTIVE I SO I. Identify and characterize the complementarity variables in the strategic projects of the irrigation water sector.

SPECIFIC OBJECTIVE II SO II. Measure and prioritize by their use and performance the complementarity variables identified in the strategic projects of the irrigation water sector.

SPECIFIC OBJECTIVE III SO III. Identify groups, among the 16 strategic water irrigation projects in the Republic of Ecuador, with similar average performance levels of the economic, environmental and social variables used in the study.

3 Methodology

The steps for this research were closely linked with the sequential implementation of the specific objectives as follows:

SO I—To identify and characterize the complementarity variables, the best sustainability practices applicable to projects in the irrigation water sector were used, obtained through a review of the scientific literature, and subject to the industry experts criteria and the authors' experience prior to their definition and final characterization.

SO II—The identified complementarity variables were measured in their State of Actual Situation through surveys to managers, executives and technical and operational staff involved in some stage of the life cycle of the 16 strategic projects of irrigation water in the Republic of Ecuador, from the year 2011 on, and their prioritization was made according to their use and practical performance to achieve project sustainability.

SO III—A hierarchical cluster analysis was performed to group projects with similar results in the average performance levels of the economic, environmental and social variables.

4 Materials and Methods

How are the Complementarity Variables identified?

Complementarity variables were identified and characterized through the review of scientific documentation containing studies on sustainability indicators. To do this, the Sustainability Reporting Guidelines G3.1 and G4 Global Reporting Initiative (2011) and (2013) were reviewed, finding 9 indicators of economic performance, 30 environmental, 14 of labor practices and work ethic, 11 of human rights, 8 of society, and 9 of product, for a total of 81. And for G4, 91 indicators in total were found. Moreover, 49 indicators for hydroelectric projects were reviewed, as suggested by Kumar and Katoch (2014), in addition to the 61 indicators reported in 22 different scientific articles, complemented with a review of studies on environmental impact of water projects. This review yielded the best sustainability practices applicable to projects in the irrigation water sector, which were subsequently filtered and validated by industry experts and the opinion of the authors. Finally, 32 variables or sustainability practices (detailed in Results Table 4) were identified.

How are the Complementarity Variables measured?

The difference between the Actual State and the Projected State, gives as a result the magnitude of the Complementarity Variable.

The Actual State of the complementarity variables measurement at a given time was obtained from surveys to experts from the irrigation water sector in the Republic of Ecuador, involved in some stages of their life cycles: planning, construction or operation. They issued their assessments and comments on 32 identified good sustainability practices, for 16 irrigation water projects; and they were compared with the Projected State, which is set based on the optimal parameters/thresholds of usage for these good sustainability practices, to stablish the state of the art in the application of these practices.

The activity levels measurement for each of the complementarity variables in their actual state was based on two parameters: the usage level and the performance level, and they were obtained from a survey designed with quantitative assessment scales. The results were compiled in a Gap Assessment Matrix with 32 variables and 2 levels of activity.

The performance level was chosen to evaluate usage quality of the variables, because being used, does not guarantee efficient use, and to that end, the following scales were used (Table 2):

The column “Do not apply” was included for those cases in which the evaluated variable was not of the interviewee’s competence, for that stage of the life cycle.

Sample size:

The study originally included 16 strategic water projects containing the irrigation component in the Republic of Ecuador which were in the planning or construction life cycle stages. At the study’s starting date, 10 were in the planning stage and the remaining 6 under construction. They constituted, at that point, the entire strategic

Table 2 Measuring scales

Level of utilization (Frequency use this practice in the project)					
Always (yes)	Almost always (yes)	Sometimes (yes)	Rarely (yes)	Never (no)	Do not apply
5	4	3	2	1	0
Performance level (How efficiently do this practice in the project)					
Excellent	Great	Competent	Need to improve	Deficient	Do not apply
5	4	3	2	1	0

Table 3 List of evaluated projects

No.	PROYEC TO
1	CONTROL DE INUNDACIONES MILAGRO CIM
	PROYECTO MULTIPROPOSITO PURUHANTA-PIMAMPIRO-YAHUARCOCHA
2	PROYECTO MULTIPROPOSITO JAMA
3	PROYECTO PROPOSITO MULTIPLE COAQUE
4	PLAN DE APROVECHAMIENTO Y CONTROL DE AGUA DE LA PROVINCIA DE LOS RIOS PACALORI
5	ESTUDIOS: PROYECTO DE TRASVASE RIO DAULE - PEDRO CARBO (INP)
6	PROYECTO MULTIPROPOSITO TUMBABIRO
7	PROYECTO MULTIPROPOSITO PUMA
8	PROYECTO CHALUPAS
9	OPTIMIZACION PROYECTO MULTIPROPOSITO TAHUIN
10	TRASVASE DAULE - VINCES (DAUVIN)
11	TRASVASE CHONGON -SAN VICENTE
12	CONTROL DE INUNDACIONES BULUBULU
13	CONTROL DE INUNDACIONES CANAR
14	CONTROL DE INUNDACIONES NARANJAL
15	MULTIPLE CHONE
16	MULTIPROPOSITO BABA

Source Public water company of Ecuador EPA

water projects that contained the irrigation component in these life cycle stages. In April 2015, the Chongón Diversion Project—San Vicente entered the operation stage. Finally, of the remaining 15 projects that were evaluated, it was not possible to assess the Puruhanta—Pimampiro—Yahuarcocha project, reported in April 2015 by the PWC public water company as non-viable; instead, the Baba Multipurpose Project (currently in operation) was assessed in its planning stage, according to details in Table 3.

Interviewed people

In order to get the more real results for the 16 studied projects, 16 surveys were distributed between project managers and professionals of both the PWC and its counterpart (construction and inspection companies) and their results, which included the pronouncement of 16 industry experts, were obtained.

How were the levels of usage and performance of the identified variables in each of the 16 water projects verified?

Based on the calculation of the different projects' average performance levels in the economic, environmental and social dimensions and using a hierarchical cluster analysis, project groups with similar variables performance levels were identified. This was done for projects belonging to the same group and different projects belonging to different groups. To this end, the between-group method and squared Euclidean distance measure were used.

5 Results

SO I. As a final result, a total of 32 complementarity variables or sustainability practices were identified, which were divided into 7 economic variables, 11 environmental variables and 14 social variables, detailed in Table 4.

Table 4 Variables of complementarity

1	*Economic practices*
1.1	Having enough reliable financial flows
1.2	Having financing for cases of unforeseen unconstructive as resettlement, rehabilitation of people affected, road construction/additional routes
1.3	Including in the initial budget funding for development of agricultural activities (crop changes and improvements, training in irrigation, increased production and marketing)
1.4	Including in the initial budget funding for plans and/or programs that contribute to generating positive economic impacts over trade, industry and tourism in the region
1.5	Including in the initial budget funding for plans and/ or environmental and social programs
1.6	Having timely funding sources
1.7	Consider public assistance and/or subsidies to fund productive activities of vulnerable groups

(continued)

Table 4 (continued)

2	*Environmental practices*
2.1	Plan or program to control the generation and disposal of waste and debris
2.2	Plan or environmental control program of the impact caused by the stream deflection (length and scope)
2.3	Monitoring the amount of slime in the stream before, during and after project implementation
2.4	Plan or monitoring program of air quality, surface/ ground water, acoustic and ground changes
2.5	Plan or program to preserve existing national parks up to a 10 km radius from the project
2.6	Plan or prevention program for environmental damage caused by mining operations in quarries
2.7	Plan or program for the preservation of ecological flow and impact on aquatic life.
2.8	Plan or preservation program for land animal and bird species
2.9	Plan or Program for identification and control of risk areas subject to natural disasters (landslides, floods, earthquakes …)
2.10	Raising awareness of climate change threats
2.11	Conducting environmental audits and socio-environmental control
3	*Social practices*
3.1	Plan or program for direct formal employment generation
3.2	Make a cadastre and theme mapping of: spatialization and spatial analysis of lack of airport infrastructure, electricity, health, tourism, industry, communication; socio-cultural analysis of health and education coverage; PEA, housing vulnerability, basic services availability
3.3	Management plan for people displaced by the project
3.4	Management plan for warm public space (parks, gardens, hospitals, schools) and other quality basic services
3.5	Plan or program for conflict resolution between local people and migrant workers
3.6	Identify and assess the impact on transport and communication means and infrastructure
3.7	Practices to prevent housing damage due to operations (blasting, earthmoving)
3.8	Actions to avoid possible time losses, movement restrictions or changes during the execution of the project
3.9	Plan or program to preserve cultural heritage of the area
3.10	Plan or program to promote community cohesion and identity as well as integration and participation of minorities
3.11	Efficient and coordinated participation and activity of local, regional and national authorities
3.12	Anti-corruption policies and procedures employee training
3.13	Include local community participation in decision-making
3.14	Plans or programs to improve the living standards of the population in the area affected by the project

Prepared by the authors

5.1 Variables Results

SO II—Results obtained from the measurement and prioritizing of variables by usage frequency and performance level are presented below.

Usage frequency of economic variables

Variable	1	2	3	4	5	6	7
Usage	16	14	11	13	15	14	15
No Usage	0	2	5	3	1	2	1
% Usage	100%	88%	69%	81%	94%	88%	94%

Usage frequency of environmental variables

Variable	8	9	10	11	12	13	14	15	16	17	18
Usage	16	13	14	13	11	13	11	12	13	12	13
No Usage	0	3	2	3	5	3	5	4	3	4	3
% Usage	100%	81%	88%	81%	69%	81%	69%	75%	81%	75%	81%

Usage frequency of social variables

Variable	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Usage	13	10	12	8	10	10	11	12	12	11	16	14	10	12
No Usage	3	6	4	8	6	6	5	4	4	5	0	2	6	4
% Usage	81%	63%	75%	50%	63%	63%	69%	C	75%	69%	100%	88%	63%	75%

HIGH LEVEL USE≥85%

MIDDLE LEVEL USE≥70% and <85%

LOW LEVEL USE<70%

Performance level of economics variables

Variable	1	2	3	4	5	6	7
Average	4.2500	4.0000	3.5625	3.5625	3.8750	3.8750	3.6875
Std. dev.	0.4472	0.5164	0.9639	1.0308	0.7188	0.6191	0.7932

Performance level of environmental variables

Variable	8	9	10	11	12	13	14	15	16	17	18
Average	4.0625	3.8000	3.7500	3.8125	3.6250	3.7500	3.6875	3.6250	3.6875	3.6250	3.6250
Std. dev.	0.4425	0.6761	0.6831	0.5439	0.6191	0.5774	0.7932	0.8062	0.7932	0.7188	0.8851

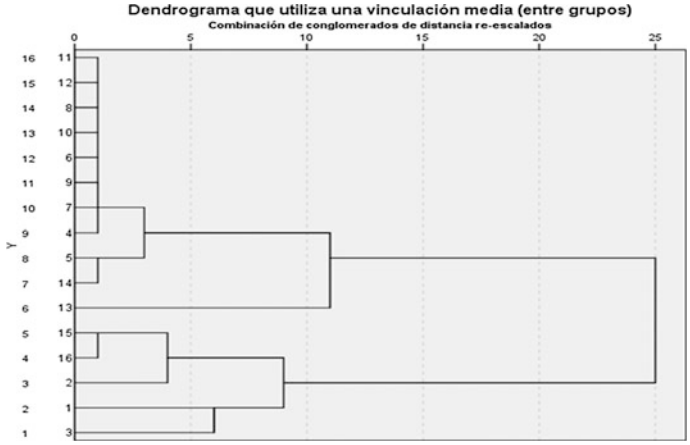
Performance level of social variables

Variable	19	20	21	22	23	24	25
Average	3.6250	3.2667	3.3125	3.0000	3.0667	3.1875	3.3333
Std. dev.	0.7188	1.2228	1.1955	1.2111	1.2228	1.1673	1.1127
Variable	26	27	28	29	30	31	32
Average	3.6000	3.2500	3.4375	3.9375	3.7500	3.3125	3.3125
Std. dev.	0.8281	1.2910	1.0935	0.2500	0.7746	0.9465	1.3022

5.2 Project Results

SO III—Two projects performance levels were obtained after the cluster analysis are shown:

Averages	Conglomerate 1	Conglomerate 2
	Projects: 4, 5, 6, 7, 8, 9, 10, 11, 12 y 13	Projects: 1, 2, 3, 14, 15 y 16
Performance economics variables	4071	3429
Performance environmental variables	4036	3220
Performance social variables	3950	2452



6 Discussion of Results

6.1 Discussion Per Variable

The results of the level of use of the 32 complementarity variables indicate that, according to experts, 19 variables have medium and high usage in situ; namely, they are used in over 70% of the projects. Only the remaining 7 variables, mostly social as shown in Fig. 1, have a low usage rate. That is to say, that they are used in less than 70% of the projects but not less than in 50% of the projects. This means, for example, for the extreme cases, that the practice or economic variable "Having enough reliable financial flows" is used in 100% of the projects, whereas the social practice of 'management of public space (gardens parks, hospitals, schools) and other quality basic services' is used in 50% of projects. These results are interpreted as a validation of the choice of practices identified by reviewing scientific literature, for 79% of practices have a high and medium level of usage and only a social practice is used only in 50% of the projects.

The results mentioned above are confirmed in Fig. 2, where a slight tendency of less use of the environmental and social variables is shown, when comparing to the economic variables. This is consistent with the evolution of the variables' use, as historically financial profitability was privileged with a clear focus on economic and financial feasibility over the environmental and social.

VARIABLES	No.		USAGE RATE IN SITU
ECONOMIC	3	Including in the initial budget funding for development of agricultural activities (crop changes and improvements, training in irrigation, increased production and marketing)	69%
ENVIRONMENTAL	5	Plan or program to preserve existing national parks up to a 10 km radius from the project	69%
SOCIAL	4	Management plan for warm public space (parks, gardens, hospitals, schools) and other quality basic services	50%
	5	Plan or program for conflict resolution between local people and migrant workers	63%
	6	Identify and assess the impact on transport and communication means and infrastructure.	63%
	7	Practices to prevent housing damage due to operations (blasting, earthmoving)	69%
	13	Include local community participation in decision-making	63%

Fig. 1 Variables with low usage rate

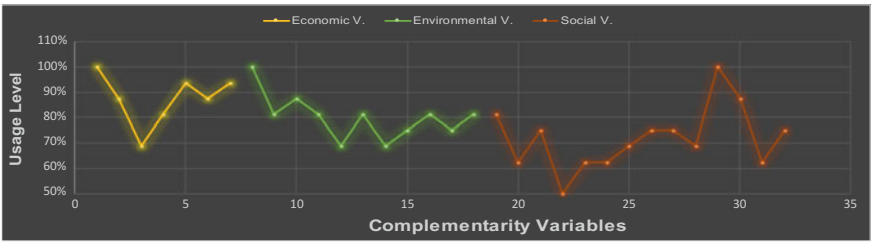


Fig. 2 Level of usage of complementarity variables

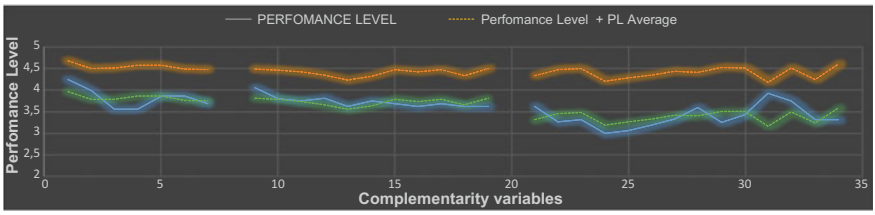


Fig. 3 Average performance level of the complementarity variables

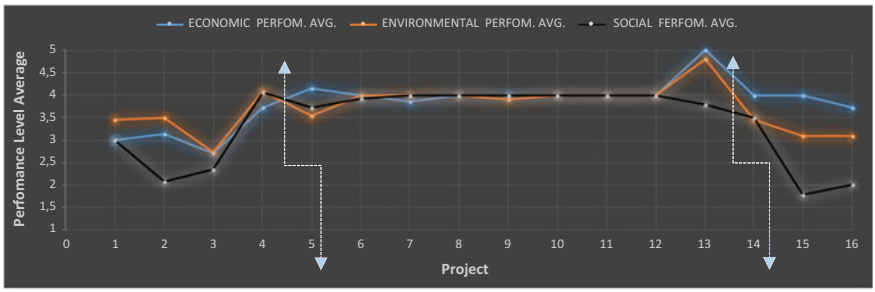


Fig. 4 Average level of complementarity variables performance per project

Figure 3 shows that the economic variable 1, which obtained a high use rate, is executed and/or implemented with the average variable efficiency within its sector, confirming the consistency of the results. The 12 variables which are not covered or not running as efficiently as the average of other variables in the sector, are respectively the following variables: Economic 3 and 4, environmental 8, 9 and 11, and Social 2, 3, 4, 5, 6, 7 and 9, coinciding mostly with low use variables. These results emphasize the need to work on their training and management. This is the case of the particular behavior of the economic variable 3 "Contemplating in the initial budget for financing agricultural development activities (conversion and crop improvements, training in irrigation, increased production and marketing)", which in addition to having a low use rate, is executed below the average level of efficiency of the variables in its sector and, therefore, generates greater risk of gaps of complementarity.

6.2 Discussion Per Project

Analysing the performance level results for each of the 16 projects, two large groups of projects were obtained. The first group comprised 10 projects which were the majority. The second group, with a clear dispersion of average performance levels as shown in Fig. 4, comprised 6 projects: 1, 2, 3, 14, 15 and 16, which have in common that they are implanted in the river basins of the Pacific slope, where

80% of the Ecuadorian population are based and where social and environmental practices have not been adequately addressed. In the second phase, by increasing the number of experts interviewed, it is expected to identify new groups of projects with similar patterns of performance level.

7 Conclusions

After reviewing the scientific literature containing sustainability indicators studies and with the input from experts in the water sector, 32 variables applicable to complementary strategic water irrigation projects were identified (7 economic, 11 environmental and 14 social).

There were only seven variables or practices that were identified by experts in the field with a low use rate, less than 70% of use: 1 economic, 1 environmental and 5 social. The remaining 24 variables that represent 79% of all variables (the majority) have a medium and high frequency of use, over 70%. These results minimize the risk of getting a wrong sustainability indicator by using 32 identified variables, ensuring the continuity of the study with a broader base of experts to interview.

From the study of the complementarity variables, in 16 projects in the Republic of Ecuador, 2 groups of projects with common characteristics were identified. The first group consists of 10 projects that have a high economic performance and moderate environmental and social performance, which for the case study was the majority (Nos. 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13). The second group, 37.5%, comprises the remaining 6 projects which have a moderate level of performance in the economic and environmental variables, and low social performance, in the case of study (Nos. 1, 2, 3, 14, 15 and 16) and they have in common that they were implemented in the water basins of the Pacific slope, where 80% of the population is based, and, therefore, the most populated water basins trigger higher social and environmental demands.

Finally, the results obtained through the behavior of the complementarity variables identified, applied to strategic irrigation projects in the Republic of Ecuador, allow encouraging the study continuity in order to develop an algorithm that calculates the gaps of unconstructive complementarity. This algorithm may be useful for policy and decision makers on such water projects, to help the sustainable development of water irrigation projects implemented in natural regions and concrete water basins of Ecuador and throughout the world in general.

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Part V
Energy Efficiency and Renewable Energies

Aging Model for Re-used Electric Vehicle Batteries in Second Life Stationary Applications

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

Abstract Energy generation and distribution around the globe expect that micro-grids, renewable and distributed energy services will be key elements in future grid infrastructures. That is why batteries, as storage energy systems, are in the scope of many studies. To counteract the high costs of Li-ion batteries appears the idea of electric vehicle battery reuse or second life for stationary applications. In fact, batteries from electric vehicles are not useful for transportation purposes after they have lost a 20% of its capacity. This study uses an electric equivalent circuit to model battery behavior and aging under five different second life applications: Fast charge of electric vehicles; isolated applications; uninterruptible power systems and Self consumption with and without participation on grid frequency regulation. The battery model takes into account temperature, C-rate, depth of discharge and voltage of the battery to evaluate and calculate battery aging along time and use. This model runs on Matlab and Simulink to determine the battery state of health evolution and, therefore, the rest of useful life, which can be used for future economic analysis and maintenance management.

Keywords Batteries · Second life · Reuse · Model · Aging

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1 Introduction

The majority of sold Electric Vehicles (EV) are equipped with Li-ion batteries to store energy (Gil-Agusti et al. 2014). As it occurs with laptops and other electronic equipment, these batteries degrade with time and use (Broussely et al. 2005). In the automotive sector, these batteries are considered not useful for traction services when they have lost between 20 and 30% of its capacity (Olivares et al. 2013). This is the end of the 1st life and it is also the point where most of the battery aging studies finish (Guenther et al. 2013).

The EV is not profitable without fiscal incentives (Mock and Yang 2014) mostly due to the high costs of batteries, 700 €/kWh. Knowing that the integration of energy storage systems to provide energy services to the electricity grid is being increasingly studied lately (Rastler 2010; Lymperopoulos 2014), car manufacturers try to enhance EV sales by re-selling their batteries at the end of the 1st life. In fact, some 2nd life battery projects already appeared, such as the EVEREST or the Second Life Battery project amongst others. Moreover, many papers and reports presented studies about its economic viability (Gladwin et al. 2013; Viswanathan and Kintner-Meyer 2011) and even some companies were created to work on them, as it is the case of 4R-energy.

All these projects try to demonstrate the technical feasibility of the EV battery re-use to store energy. At the same time, they expect to determine their batteries Rest of Useful Life (RUL) during the 2nd life in order to be able to offer credible guarantees. This last concept, the RUL determination during their 2nd life, is what this study analyzes by means of an equivalent electric circuit model of the battery.

Many authors have extensively studied dynamic battery models. There are simple models using only one resistance (R) and a pair of resistance and capacitor in parallel (RC) (Zhang and Lee 2011; Cho et al. 2012), or more complex models using Change Phase materials and coils (Liu et al. 2011; Osaka et al. 2012). However, the base of these models is the same: the addition of elements into the model incorporate functional particularities and the results accuracy is improved (Guenther et al. 2012).

These models are completed by the addition of the aging effects to determine the RUL under certain current loads. The main factors that accelerate or reduce batteries' aging are: Temperature (T), Depth of discharge (DOD), State of charge (SOC) and intensity rate (C-rate) (Barré et al. 2013; Eddahech 2013; Vetter et al. 2005).

These batteries age either while stored (Calendar aging) or under use (Cycling aging). Regarding the calendar aging, apart from time there are two other factors that participate in the aging of batteries: Temperature and SOC. Temperature effect follows an exponential behavior described by the Arrhenius equation. On the other hand, SOC effect, which may also be implemented using the battery voltage, has a linear effect (Schmalstieg et al. 2014; Delaille et al. 2013).

Cycling aging has two additional parameters to consider: DOD and C-rate (Guena and Leblanc 2006). DOD effect follows a logarithmic relation, while the

C-rate effect is described by a second degree polynomial expression (Lam 2011; Sarasketa-Zabala et al. 2013).

In practice, these relations have two main consequences: An internal resistance increase R_0 and a loss of capacity (Niehoff et al. 2013). Although there are other effects on the RC pairs regarding the instant response of a battery, they are not relevant for RUL estimations and are not implemented in this model.

As the empiric experimentation with batteries for each possible application requires of much time and it is expensive, a battery equivalent electric model parametrized using literature and experimental data from laboratory tests simulates the battery aging. The results of the simulations will provide an illustrative lifespan of batteries under different loads in a fast and economic way.

2 Objective

The main goal of this study is to determine, using an electrochemical model, the estimated lifespan or durability of a battery in different 2nd life applications. These applications are classified in four groups regarding the characteristics of the battery loads.

The estimated RUL will serve to define and program battery replacements and to determine its impact in the amortizations and business cost analysis.

3 Methodology

For the RUL calculation, an electric equivalent circuit model with an R and 4 RC pairs in series will be used, as it is shown in Fig. 1. The OCV element represents a voltage source that establishes the open circuit voltage of a battery in relation to SOC. These parameters are taken from the battery manufacturer datasheet.

Equations 1 and 2 describe the dependencies between the aforementioned calendar and cycling capacity loss and the aging factors.

$$C_{loss\_cal} = f(V, T, t) \tag{1}$$

$$C_{loss\_cyc} = f(I, V, DOD, T, t) \tag{2}$$

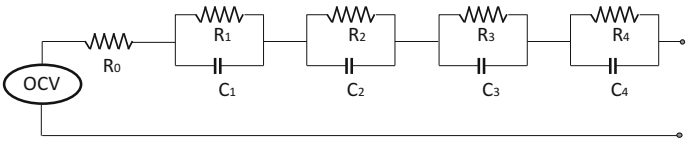

Fig. 1 Electrochemical circuit used, it has a resistance and four RC pairs in series

The calendar capacity fade is mathematically expressed by Eq. 3, which incorporates Temperature, SOC or voltage (V) and time (t) factors.

$$C_{loss\_cal} = (\beta_1 + \beta_2 \cdot V) \times 10^6 \cdot e^{\frac{\beta_3}{T}} \cdot \sqrt{t} \tag{3}$$

On the other hand, the cell cycling capacity fade has, additionally, current (C-rate or I) and DOD factors. In this model, the cycling capacity fade rate is based on the degradation observed under continuous discharge and charge cycles at 1C (being 1C the current intensity corresponding to a complete discharge of a battery in one hour), 273 K, 50% average SOC and 100% DOD. Equations 4–7 adjust the model degradation in relation to the aging factors.

$$I_{ef} = \theta_1 \cdot I^2 + \theta_2 \cdot I + \theta_3 \tag{4}$$

$$V_{ef} = \theta_4 \cdot V + \theta_5 \tag{5}$$

$$DOD_{ef} = \frac{Log_{10}(DOD)}{2} \tag{6}$$

$$T_{ef} = \frac{e^{\frac{\theta_6}{T}}}{e^{\frac{\theta_6}{298}}} \tag{7}$$

Parameters β_1, β_2, β_3, θ_1, θ_2, θ_3, θ_4, θ_5 and θ_6 should be determined for each battery type. Figure 2 presents a graphic representation of these equations in our case.

The electrochemical model runs on MATLAB® and uses Simulink® tools and libraries. Figure 3 presents a block-like schematic representation of the model. The model inputs are the current loads and temperature. These inputs are defined by the 2nd life applications requirements. At their entrance, the model calculates the

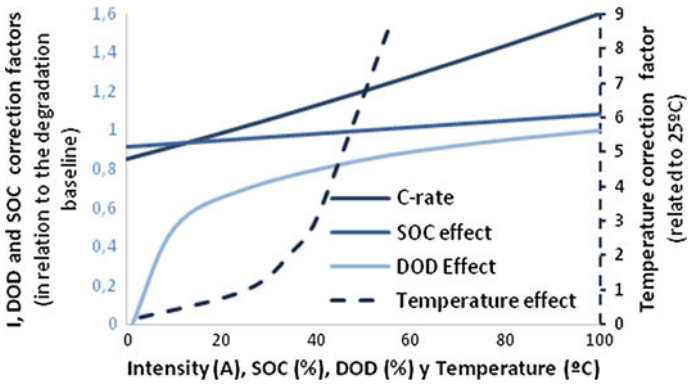

Fig. 2 Effects of the different aging factors in relation to the baseline discharge rate at 25 °C, 1C and 100% DOD cycles

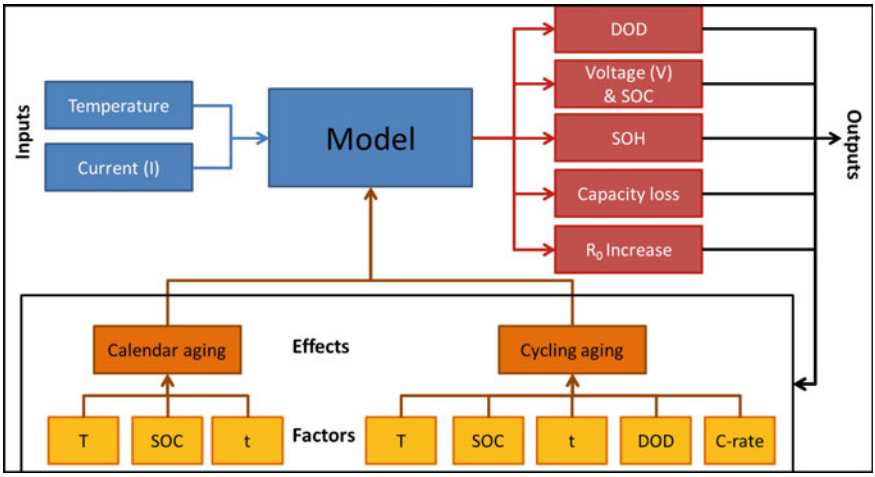

Fig. 3 Block-like schema of the electrochemical model implemented

electric instant response of the battery, providing the following outputs: Voltage (V), SOC and DOD variations, Capacity fade, State of Health (SOH) decrease and internal resistance R_0 increase. These outputs re-enter into the model as feedback or closed loop inputs for the subsequent iterations. This loop is necessary to obtain precise battery aging and performance responses.

Knowing that the main consequences of aging is the capacity loss, the state of health is then calculated as the ratio between the actual battery capacity (Cap) and the initial battery capacity (Cap_{ini}) as it is expressed by Eq. 8. The SOH will be further used to determine the functional end of the second life (Nuhic et al. 2013; Zou et al. 2015).

$$SOH = Cap/Cap_{ini} \tag{8}$$

Moreover, from empirical laboratory tests results, a second order polynomial expression (described by Eq. 9) was obtained relating the SOH with the internal resistance increase (R_0 in the model from Fig. 1). This polynomial relation is consistent compared to other studies with similar conclusions (Dai et al. 2009).

$$R_0 = \alpha_1 + \alpha_2 \cdot SOH + \alpha_3 SOH^2 \tag{9}$$

This R_0 value determines the battery efficiency degradation and quantifies the energy loss, which is basically caused by Joule effect, expressed by Q[J] in Eq. 10 (Jossen 2006; Braun et al. 2012). Obviously, the energy losses are higher at higher C-rates.

$$Q = R_0 \cdot I^2 \tag{10}$$

To determine the moment when these batteries are not capable to offer the energy that each application needs the model simulates the battery performances under the different use cases and loads, which are:

- Self consumption in residential or commercial environments: These systems are based in the "peak shaving" energy concept. The objective is to reduce the annual electricity bill by storing energy during low tariff hours to use it during high tariff hours and, at the same time, reduce the power tariff contracted. If there are renewable energy systems connected to the micro grid, the storage device can store this energy when the production is higher than the demand. The system load simulation represents a daily full charge and discharge cycle. The average energy consumption in Spanish houses is the energy considered for this simulation, which corresponds to 10 kWh/day.
- Island installations: In this case, as the system is not connected to the electricity grid, the energy storage device should be able to provide energy during the hours when there is no energy production. Additionally, it has to be over-dimensioned in order to ensure electricity power during three days, for the exceptional cases when there cannot be enough energy production (i.e. cloudy days for photovoltaic systems). The same daily energy consumption than in the previous case was considered. Therefore, the energy storage system should have a capacity of 50 kWh. In this use case, the charge and discharge cycles have a 30% DOD.
- EV fast charge: The fast charge of EVs requires power levels near 50 kW. The EV fast charge seriously stress the local network during the first minutes. This effect has been studied by De Hoog et al. (2013), Maitra et al. (2013). An analysis of 2nd life energy storage devices to provide the additional power needed is done to eliminate or delude the stress and to reduce the costs of these high power installations. The 2nd life battery load follows a slow charge and a fast discharge cycle. The battery capacity considered for this application is the same as the one used in the vehicle, that is, 20 kWh. This case assumes two fast EV charges (or cycles) per day.
- Uninterrupted Power Systems (UPS): These type of systems offer energy during around 15 min until the electricity grid power is re-established or other power sources are active. They are often used in telecommunications and data centers, where sudden stops are not conceivable. The battery load cycle follows a slow charge, then the battery system stays completely charged during long periods of time (10 days in this case) and then it suffers a fast discharge. Although the energy capacity of these systems may substantially change from one to another installation, this study case considers only 10 kWh.

Table 1 summarizes the main characteristics of these four applications. It should be emphasized that, for one side, the End of Life (EoL) is reached when the battery SOH decreases to 60% in all applications except for the self-consumption case,

Table 1 Simulation battery 2nd life load cycle characteristics

Application	Initial SOH (%)	Final SOH (%)	Initial DOD (%)	C-rate	Average SOC (%)
Self-consumption	80	40	85	C/20	50
Island	80	60	30	C/75	85
EV fast charge	80	60	85	1.5C	82
UPS	80	60	85	2C	90

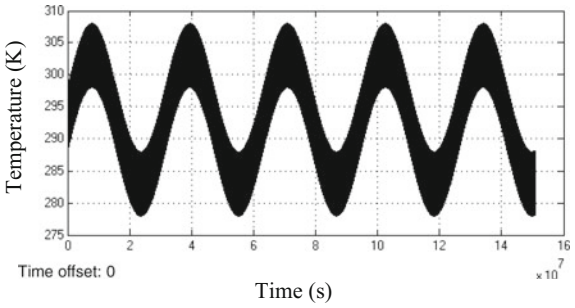

Fig. 4 Annual temperature cycle with ±5 °C daily variations

where it goes until a 40% SOH. In this particular case the capacity loss influences only in the revenue obtained and it is not critical for the normal functionality as it occurs in all other applications. On the other hand, the DOD used for the simulation is 85%, which is the limitation inherited from the EV battery pack for security and safety reasons.

Batteries should be placed under controlled and enclosed environments for the RUL calculations. Hence, the assumption that temperature changes will be soft and away from extreme situations is taken. Accordingly, two possibilities were analyzed in this study: A constant temperature case at 25 °C (298 K) and a temperature year cycle that goes from 10 to 30 °C (283–303 K) with ±5 °C daily variations as it is shown in Fig. 4. The first possibility considers that an active cooling and heating system controls the temperature. The second case has no temperature control. This was done to evaluate if there is a noticeable change in the RUL evolution with or without temperature control. In fact, cooling systems consume energy and cost money, thus, it is preferable to avoid them.

On the economic side, from the results obtained in a previous work (Canals Casals et al. 2014) and from the study by Neubauer et al. (2012) it is considered that reused batteries cost around 100 €/kWh. The battery acquisition cost is obtained by the multiplication of this value and the battery capacity (kWh) needed in each 2nd life application. With this and the simulated RUL results, the minimum amortization costs will be calculated.

4 Results

This section starts with the presentation of the SOH evolution resulting from the simulation at 25 °C constant temperature. The departing SOH is 80%, as this could be the real state of health when batteries leave the vehicle and start their second life. Figure 5 shows, effectively, that the applications with higher C-rates and frequent discharges, like the EV fast charge, age faster. In fact, the battery will last only 1.7 years on EV fast charge applications, while in less demanding applications, like UPS, the battery lifespan is expected to be longer than 24 years. Moreover, the second application with longer lifespan is the island installation, which has low C-rates. Notice that, as it is also appreciable in Fig. 5, the final SOH for self-consumption is 40% and its RUL almost doubles the 60% SOH in comparison.

A deeper analysis of the results shows that the impact of calendar and cycling aging is not constant for all cases. In fact, the calendar degradation becomes more relevant as the battery RUL is longer. This is presented in Fig. 6 by a bar diagram. Accordingly, the UPS and island applications, which are the ones with longer RUL, have a calendar aging impact of 27 and 18% respectively. On the other hand, the applications with less than 10 years' lifespan have a cycling aging impact higher than 95%.

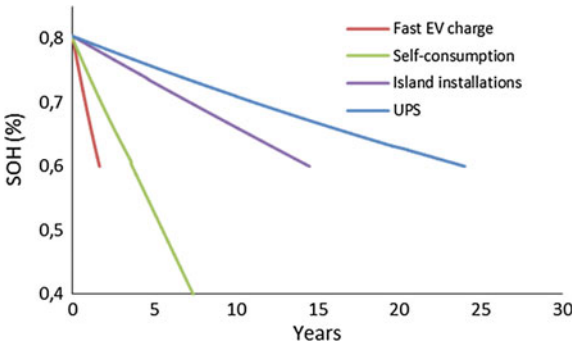

Fig. 5 Battery SOH evolution under different 2nd life applications at 25 °C

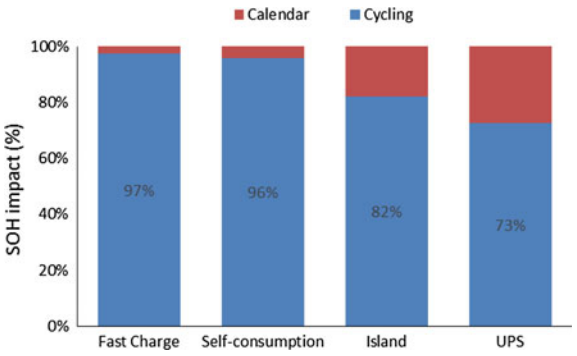

Fig. 6 Impact of the cycling and calendar aging on the final SOH

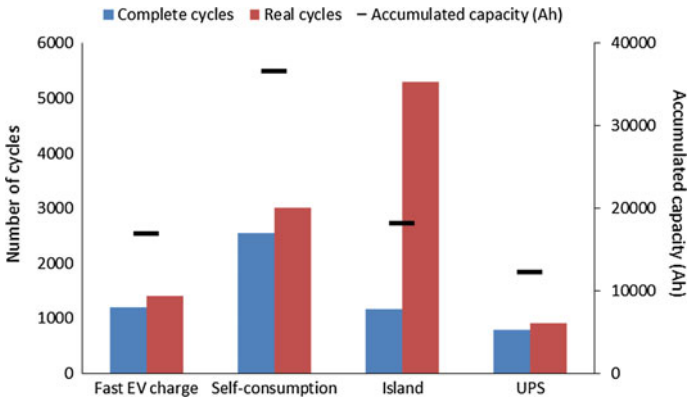

Fig. 7 Number of cycles done per battery and total accumulated capacity discharged on each 2nd life application

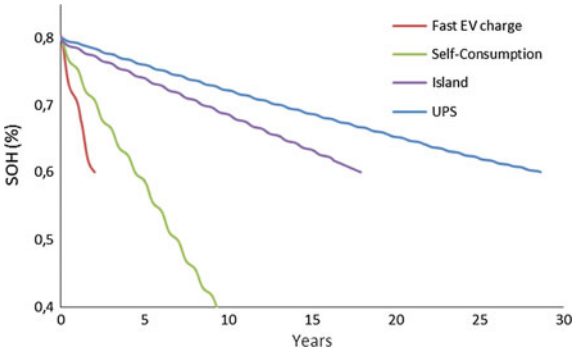

Fig. 8 Battery SOH evolution under different 2nd life applications at variable temperature

The results presented in Fig. 7 allow to identify which is the impact of DOD and C-rate by the quantity of cycles and accumulated capacity exchanged (Ah). The black line in Fig. 7, that represents the total amount of accumulated capacity discharged, shows that the self-consumption application is the one with more energy exchanges. Again, notice that its final SOH is 40% instead of 60%. The UPS application is the one doing fewer cycles and, although being the case with longer lifespan, it is the case having less energy exchanges. Correspondingly, it is the case with lower cycle aging impact, as presented in Fig. 6. The explanation is due, basically, to the battery cycling only during 1.5% of time and resting fully charged afterwards. Additionally, when it finally cycles, it does it under the higher current exigencies studied.

Figure 7 also shows the number of cycles that batteries may do during these 2nd life case studies. Looking carefully to the complete equivalent cycles (which translates the cycles done to 100% DOD cycles), it can be appreciated that

self-consumption does 2551 cycles, while others do not achieve 1200 cycles or, in the worse performing case, the UPS finishes after doing only 785 complete cycles.

Using Eq. 9, the final R_0 results indicate that it increases by 74%, reducing significantly the final battery efficiency.

RUL increases around a 20% in all the studied cases when applying a variable temperature cycle. Additionally, the SOH evolution presents a sinusoidal behavior, which corresponds to the annual temperature cycle. Nonetheless, the daily temperature cycle is not appreciable at the presented timescale. Figure 8 shows the obtained results.

The longer lifespan is explained because the working temperature passes more than 2/3 of time below 25 °C. Obviously, if these premises change, the results will change accordingly.

This longer RUL has a direct effect on cost analysis, on maintenance intervention and on investment amortization.

Table 2 reflects the aforementioned economic impact of RUL changes for each application. For example, fast EV charging applications with controlled temperature need to replace batteries in less than 2 years, which implies 1200 €/year in amortization in order to have enough cash to buy new batteries when it is needed. Additionally, Table 2 presents the amortization in relation to the kWh installed, in order to evaluate the costs per energy storage unit.

Additionally, Table 2 allows to compare the obtained results with and without temperature control. Therefore, considering the amortizations all along the battery lifespan, it should be highlighted that their value decreases by the lifespan

Table 2 Results and cost summary

At 25 °C				
	Fast EV charge	Self-consumption	Island	UPS
Endurance (years)	1.7	7.4	14.5	24.0
Minimum capacity of the battery (kWh)	20	10	50	10*
Battery cost (€)	2000	1000	5000	1000
Yearly amortization (€)	1199	135	345	42
Yearly amortization per kWh (€/kWh)	60	14	7	4
No temperature control				
Endurance (years)	2.0	9.3	17.9	28.6
Minimum capacity of the battery (kWh)	20	10	50	10
Battery cost (€)	2000	1000	5000	1000
Yearly amortization (€)	994	107	279	35
Yearly amortization per kWh (€/kWh)	50	11	6	4
Reduction (%)	17	20	19	16

* Notice that, contrarily to other applications, the UPS had a great capacity variability, which goes from phew kWh to MWh. 10 kWh were taken in this study to have a similar order of magnitude with the rest of applications.

enlargement due to the non-controlled temperature cycle between 10 and 30 °C in relation to the 25 °C controlled case. In fact, these reductions may reach the 20% in the best case.

5 Conclusions

The economic viability of using batteries to store energy depends enormously on the battery price and lifespan.

The use of 2nd life batteries allows a reduction on the first aspect, the battery price, being necessary to evaluate the durability of these batteries in stationary applications.

This study showed how the battery lifespan not only depends on the number of cycles but also on the working conditions. Hence, battery lifespan goes from 1.7 years on Fast EV charge applications and almost up to 29 years on UPS applications.

One of the key factors affecting the battery lifespan is temperature. Therefore, it has been observed that the battery life length enlarges a 20% if the temperature oscillates between 10 and 30 °C instead of being controlled and fixed at 25 °C using air cooling systems.

Consequently, there is no need to include active cooling and heating systems in the battery location if it stays within this range of temperatures. This reverts in an important investment reduction (no need to purchase and install any cooling system) and an improvement on efficiency and functional costs as there is no energy use to cool down or heat up the room. In fact, not controlling the room temperature reverts in a reduction between 15 and 20% of the battery amortizations for replacement due to the rest of useful life enlargement.

These aforementioned amortization costs oscillate between the 994 and the 1200 €/year in EV fast charge applications while it reaches only 35–42 €/year in UPS applications. Additionally, self-consumption and island applications require annual amortizations around 120 and 300 € respectively.

Finally, applications with heavier working conditions have lower duration and fewer cycles. Thus, foreseeing optimal results, studies based on oversized systems bringing lower C-rates and DOD should be carried out until the optimum result between initial investments and business revenues is obtained.

The presented battery-aging model allows the evaluation of the expected RUL of batteries under different working conditions in a short period of time and with precision. The RUL results are necessary to evaluate the corresponding business models using energy storage systems.

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Assessing the Energy Saving Potential for Building Stock and Choice of Rehabilitation Strategy by a Multicriteria System

Sergio Muñoz Gómez, Sagrario Conejero, Bernardino Morillo Merino, Rubén Gregori and José-Luis Vivancos

Abstract The realities of the current economic situation along with the potential for energy savings have led energy and economic policies to postulate retrofitting existing buildings; the business sector has also followed suite, as retrofitting creates commercial opportunities for companies. However, the lack of criteria for choosing an adequate energy retrofitting strategy proved to be problematic; the European Project E4R was created in order to address this problem. The Project developed a software tool, called E4RSIM, capable of easily quantifying potential building energy savings and assessing the digital model generated from cadastral information and a database of construction systems and facilities. This tool takes two factors into account in choosing the adequate retrofitting strategy: energy consumption and investment costs. However, there were other factors of interest; e.g. the embodied energy of the materials used or the disturbances caused by construction tasks to users. This tool has evolved as part of the EDEARenov project by calibrating the energy analysis results of existing buildings, and incorporating environmental and social criteria to choose the right strategy in each case.

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1 Introduction

When designing and defining the ideal composition of both the building's envelope and systems, the criteria oriented to improve their thermal performance must be taken into account. However, this approach itself is not enough. Since the construction sector hugely influences the consumption of economic and environmental resources (materials, energy, CO_2 emissions, etc.), further sustainability-based analyses need to be done urgently.

The Brundtland Report (Brundtland 1987) defined sustainability as sustainable development, and sustainable development as *development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*

Sustainability in the construction sector seeks to balance the environmental, economic and social impacts generated by construction materials and buildings. Thus, improved refurbishment is sustainable when these impacts are minimized throughout the useful life of buildings.

In the last 20 years, numerous labels and certificates of sustainability have appeared, which certify a building's sustainability rate (Nguyen and Altan 2011). BREEAM®, LEED® and Verde®, among others, are widely acknowledged and set a recognizable standard for sustainable development. The main problem with using these labels and certificates is the technical difficulty of carrying them out and the complexity of the entire process, which is only feasible if all the information needed to assess the building is available: provenance of its materials, detailed energy consumption or details of the installations system, among others.

By bearing this in mind, and taking the tool that assesses the potential energy saving of existing buildings (developed in the European Project E4R) as a starting point, a decision was made to develop this tool (now called EDEASim) as part of the European Project EDEARenov, capable of assessing the selection of the appropriate refurbishment strategy using a multicriteria system. This system values the economic, social and environmental impacts of the buildings.

EDEAsim intends to be a simplified tool to serve both users, that is, owners of homes and technical persons, without sacrificing data accuracy (EDEASim 2015).

2 Characterization of the Analysis Scenario

There are several studies about how to characterize a building in order to assess its energy behavior; i.e. Braulio et al. (2014) or Dascalaki et al. (2011). In this case, the analysis scenario was characterized using four main blocks.

2.1 Weather

Weather has a direct impact on people's health and activity levels. While comfort conditions are not achieved with those desired, human beings need energy to balance their own energy systems. A building can use natural resources (water, sun, materials and wind) to achieve thermal comfort, in which case the environmental impact is lessened as it does not use mechanical parts or equipment, e.g. air conditioning, to achieve a balance with the environment.

Climate can be characterized by a large number of climatic factors: temperature, precipitation, relative humidity, hours of sun and solar radiation. All of these factors have a certain degree of influence on how buildings are built.

The main climate factors that most strongly influence buildings in comfort terms are temperature, precipitation, humidity, insolation and radiation.

2.2 Activity

The activity of a building or a zone is determined by the activities carried out in it after its commissioning. It affects various factors, including energy demand, occupancy rate, and the need for comfort and, consequently, hours of equipment use.

Building activity can be classified as residential, institutional, commercial or industrial.

2.3 Building Envelope

According to the Código Técnico de Edificación (2006; Spanish national regulation on energy efficiency in buildings), the thermal envelope of a building is composed of all enclosures or building systems that limit living spaces with the outside environment (air or land or other buildings), and of all the interior partitions that separate living spaces from non-living spaces which, in turn, come into contact with the outside environment (Fig. 1).

Constructive systems of the building envelope can be horizontal or vertical, and thermal behavior is determined by the following parameters:

In the walls and the hidden part in decks:

- Thickness "t" (m)
- Thermal conductivity "λ" (W/m K)
- Density "ρ" (kg/m^3)
- Specific Heat "SH" (J/kg K).

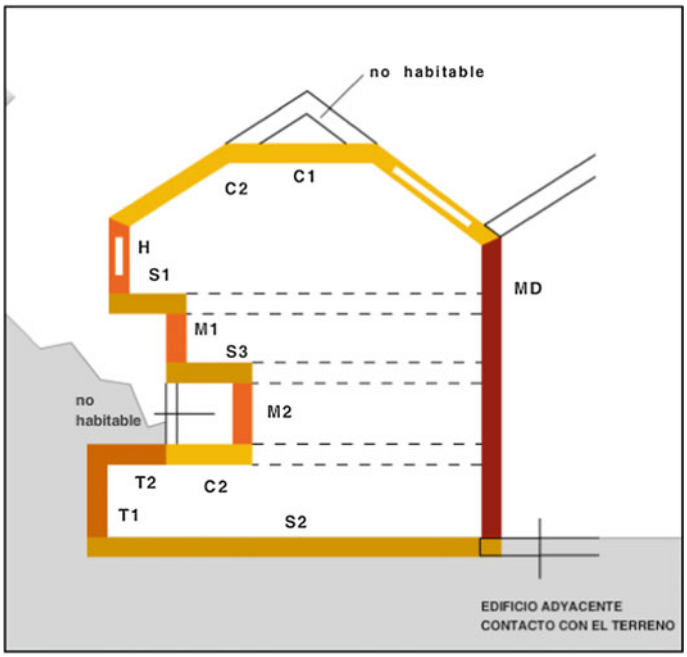


Fig. 1 Scheme of the building envelope

In the cavities and the skylights:

Thermal transmittance "U" (W/m^2 K), defined as the heat flux at the steady state divided by the area and the temperature difference of the environment on either side of the element under study, in accordance with the Código Técnico de Edificación (2006).
The solar factor "g" represents the fraction of heat gain due to solar radiation that the system directly transmits, added to the portion absorbed and re-emitted to the interior of the building, by the system.
Absorptivity "α", is defined as the amount of solar radiation that a material is able to absorb.

2.4 Facilities or Technical Equipment

The building's facilities or equipment permit(s) it to acquire thermal comfort conditions despite existing weather conditions. In this way, facilities respond to the energy demand caused by the other above-described elements.

The set of facilities that form part of the building and are related to thermal comfort are:

- Air-conditioning system: cooling and heating
- Lighting
- Domestic Hot Water
- Ventilation.

3 Tool for Potential Energy Savings Assessment Through Retrofitting: Methodology and Results

Most homeowners are unaware of their potential energy savings and the economic cost of retrofitting strategies to calculate the amortization period. So, one of the main objectives of the European Projects E4R and EDEARenov was to provide an Energy Assessment Tool accessible to users with no technical knowledge and capable of suggesting the most appropriate retrofitting strategy in each case.

To achieve this, a tool capable of generating a digital model of the building has been developed, which contains the information needed to analyze its energy performance through a calculation engine.

After analyzing several calculation engines, and even studying the development of the authors' own engine, based on regulatory processes, EnergyPlus was chosen for its international credibility, software development environment, fast simulation and the possibility of execution on a web server.

The EDEASim Tool operation scheme, as shown in Fig. 2, consists of: defining the building under study, modeling it digitally, simulating its thermal and energy behavior and, finally, analyzing the results.

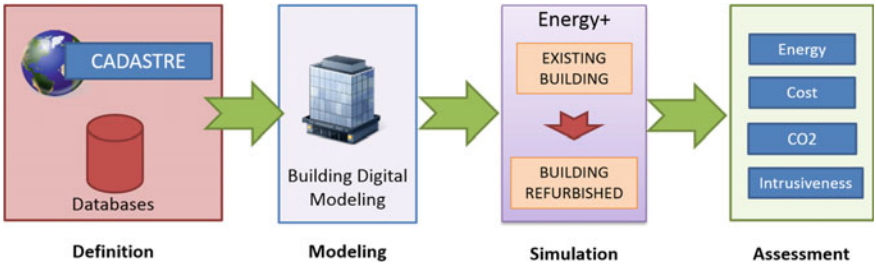


Fig. 2 The EDEASim tool operation scheme (EDEASim 2015)

3.1 *Defining the Building*

The main requirements for the tool were to achieve a high level of usability by minimizing data inputs by users. In order to generate the digital model of the building, there were two sources of information: National Cadastre, to generate the building's geometry, and a large database of constructive elements, which was specially developed.

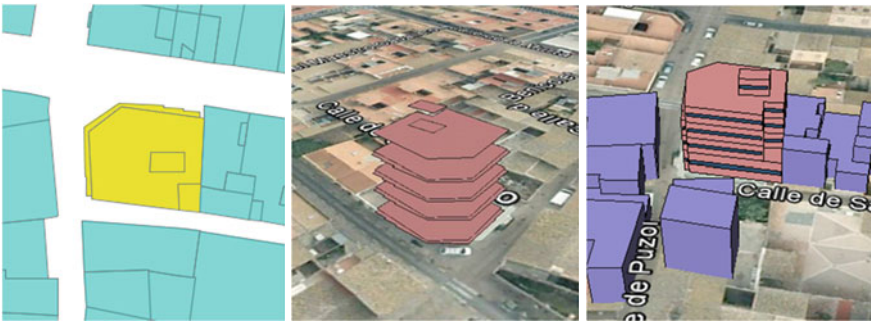
3.1.1 Cadastre

A lot of the information necessary to assess the thermal behavior of a building can be obtained from several Internet Services. In Spain, through the Cadastre Electronic Office ("Sede Electrónica de la Dirección General de Catastro"), using the address of the building, provides the following information: geographical coordinates, activity, orientation, number of floors, year of construction, and even the geometry of the building and its surrounding to estimate and calculate its shading.

By processing the vector files downloaded from Cadastre, EDEASim is able to identify facades, indoor walls or roofs (EDEASim 2015).

The process of transforming the vector files from Cadastre to a digital model with the building's geometry can be done by the following steps:

i. The vector map of a city is divided into layers. Three of these layers contain geopositioned polygons and are linked to a set of attributes: MASA, PARCELA and CONSTRU.
ii. Some polygons related to the building under analysis are obtained: block, plots and subplots (Fig. 3a).
iii. The number of floors of each subplot is obtained.



(a) Identification of polygons **(b)** Generation of floors **(c)** Generation of envelope

Fig. 3 The building geometry generation process

iv. Surfaces of floors are generated from the subplots by considering the number of floors in each one (Fig. 3b).
v. Outdoor walls are generated by connecting the vertices of adjacent floors.
vi. The typology of a wall is identified by comparing the building envelope with the plot and block polygons.
vii. Finally, windows are created on the facades (Fig. 3c).

In order to generate a digital model of the surrounding buildings, which may influence the shading of the building under study, steps i through v must be repeated in nearby plots.

3.1.2 Database

The existing buildings and their materials and facilities were analyzed in the European Projects E4R and EDEARenov.

This information was included in a large database, which contained:

- Building types
- Kinds of outdoor and indoor walls, floors, roofs and windows
- Kinds of facilities: hot water, heating, cooling, ventilation, lighting
- Retrofitting strategies.

EDEASim uses this database to identify the materials and facilities of the building based on the year of construction (Fig. 4).

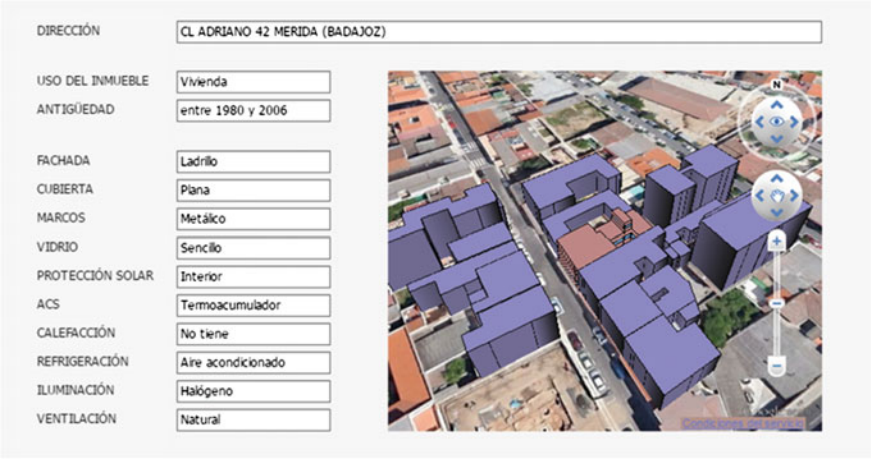


Fig. 4 Summary data of the building under study (EDEASim 2015)

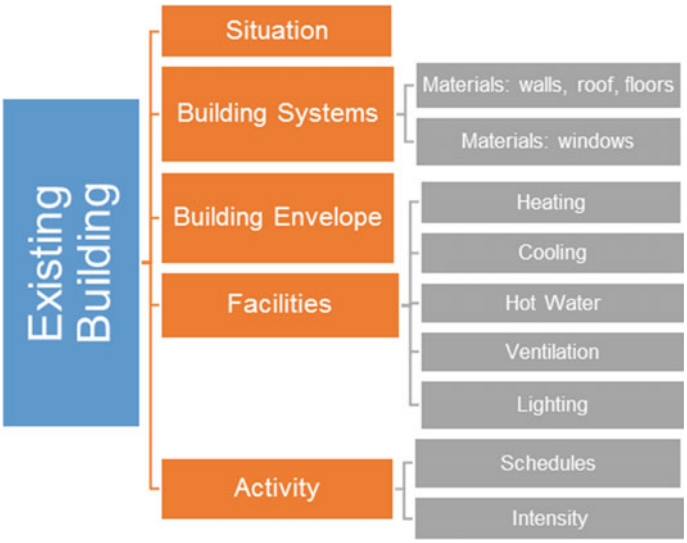


Fig. 5 Arrangement of the building digital model data

3.2 *Digital Modeling of the Building*

The digital information generated has to be structured in a particular way in order to assess the building's energy performance by a calculation engine.

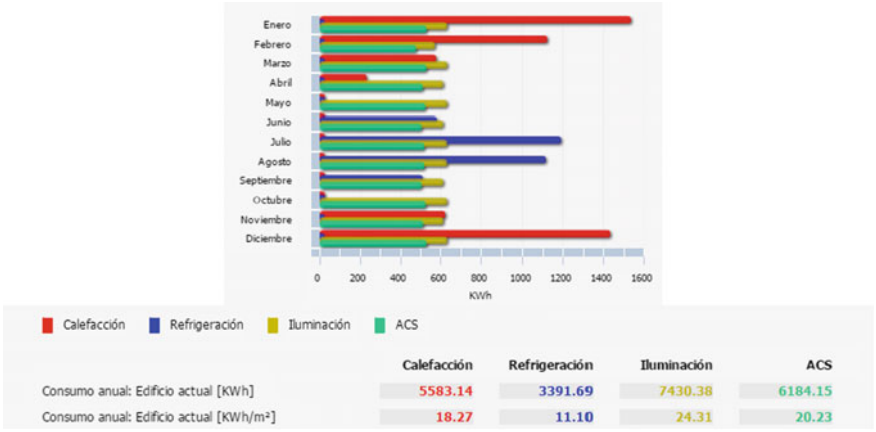
Therefore, in this case, by taking the relevant factors in the analysis as a starting point, the information was arranged as shown in Fig. 5.

With this information, the text file well-structured with the .idf extension can be generated. This file will be used as an entry element to the EnergyPlus calculation engine.

3.3 *Simulating the Building's Thermal and Energy Performance*

As discussed above, EnergyPlus was chosen as the calculation engine to assess the building's thermal and energy performance. EnergyPlus requires two files as input to perform simulations: the .idf file, which contains information on the existing building and the climate .EPW file, which contains the climatological information of the location of the building being analyzed (temperature, humidity, and solar radiation) for 365 days a year.

The simulation result is the annual energy consumption (kWh) per source—hot water, heating, cooling and lighting—as shown in Fig. 6.



	Calefacción	Refrigeración	Iluminación	ACS
Consumo anual: Edificio actual [KWh]	5583.14	3391.69	7430.38	6184.15
Consumo anual: Edificio actual [KWh/m²]	18.27	11.10	24.31	20.23

Fig. 6 Annual energy consumption for the existing building

3.4 Multicriteria Analysis of Retrofitting Strategies

After assessing the energy performance of the existing building, EDEASim calculated the impact of passive and active retrofitting strategies (EDEASim 2015). This impact was analyzed using different criteria, which helps users select one strategy or another depending on the ultimate goal—energy savings, economic (investment and amortization costs), environmental impact and social impact.

For economic, environmental and social analyses, a score for each indicator was established. This score ranged from 0 to 10: 0 indicating no improvement after applying retrofitting strategies and 10 indicating maximum improvement.

3.4.1 Energy Assessment

The energy assessment was performed by comparing the results of the dynamic simulation for the existing building and the refurbished one. This comparison (see Fig. 7) was made in terms of annual and monthly (kWh) energy consumption, distinguished based on the source of consumption—heating, cooling, lighting and hot water.

3.4.2 Economic Assessment

The economic assessment was made by taking into account the cost for applying retrofitting strategies. To quantify this, the following indicators were defined:

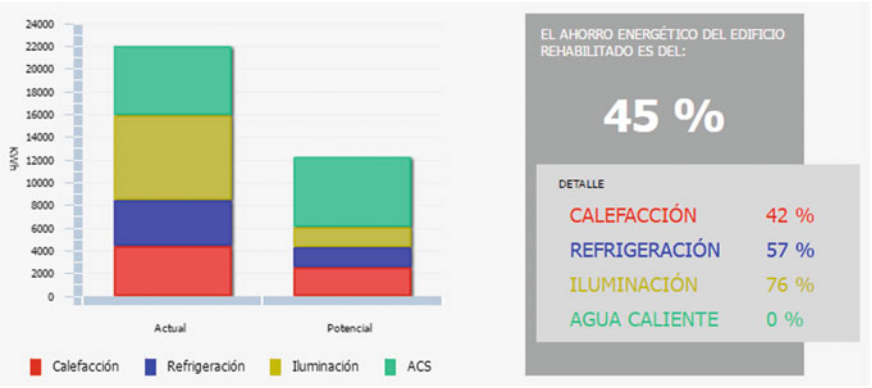


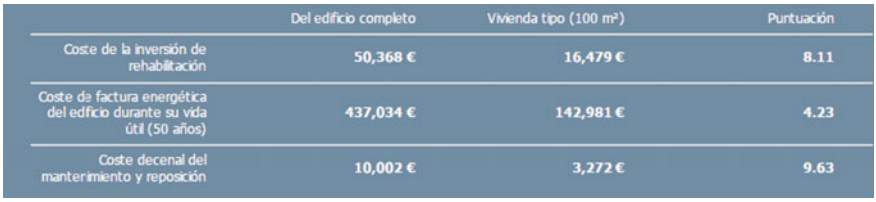
Fig. 7 Energy consumption of the existing building/refurbished building

- I1, retrofitting investment costs by taking into account the total refurbished area STreh, and the cost of construction tasks, PD, in accordance with the Construction Prices Database of the Government of Extremadura (2012).
- I2, cost of the building's energy bill during its life cycle, taking into account energy price P provided by the IDAE (2010).
- I3, decennial cost of maintenance, which is calculated by applying a coefficient of maintenance, CM, during the building's life cycle (50 years). Medium maintenance was considered in accordance with the document prepared by the Instituto Tecnológico de la Construcción de Cataluña.

Table 1 shows the method used to calculate economic indicators, and Fig. 8 provides the results obtained for a use case.

Table 1 Economic indicators

Economic impacts			
Indicators	I1, retrofitting investment cost (€)	I2, energy bill during life cycle (€)	I3, decennial maintenance cost (€)
Calculation methodology	STreh·PD	[(CEF ref·Pref) + (CEF cal·Pcal) + (CEF ACS·PACS) + (CEF Ilu·PIlu)]·50	STreh·CM
Sources	Prices database of the Government of Extremadura	EDEASim simulation IDAE (2010)	ITEC maintenance database



	Del edificio completo	Vivienda tipo (100 m²)	Puntuación
Coste de la inversión de rehabilitación	50,368 €	16,479 €	8.11
Coste de factura energética del edificio durante su vida útil (50 años)	437,034 €	142,981 €	4.23
Coste decenal del mantenimiento y reposición	10,002 €	3,272 €	9.63

Fig. 8 Economic assessment of the existing building/refurbished building

3.4.3 Environmental Assessment

Some environmental indicators were chosen for the building's life-cycle phase, as well as sources of information to calculate them:

- I4, Energy Consumption in manufacturing the materials used in the construction phase: energy impact is quantified by taking into account the total area refurbished, STreh, and also the materials embedded energy, EE, from the BEDEC Database (ITEC 2012).
- I5, Building Energy Consumption during its life cycle: energy impact is quantified by taking into account the total building energy consumption, CEF (heating, cooling, hot water and lighting), in the building's area for 50 years.
- I6, Building CO_2 Emissions during its life cycle: energy impact is quantified by taking into account the value of the primary consumption energy by simulation, converted into CO_2 emissions using the conversion factors, as FC, published by the IDAE (2011). These factors are updated regularly in accordance to the average annual energy production features.

Table 2 shows the method used to calculate the environmental indicators, and Fig. 9 provides the results obtained for a use case.

Table 2 Environmental indicators

Environmental impacts			
Indicators	I4, energy consumption in the manufacturing of materials (kWh)	I5, building energy consumption for 50 years (kWh)	I6, building CO_2 emissions for 50 years (Kg CO_2)
Calculation methodology	STreh·EE	(CEF Cal + CEF Ref + CEF ACS + CEF Ilu)· SU·50	[(CEF cal· FC CO_2 Cal) + (CEF ref·FC CO_2 Ref) + (CEF ACS·FC CO_2 ACS) + (CEF Ilu·FC CO_2 Ilu)]·50
Sources	BEDEC database (ITEC 2012)	EDEASim simulation	EDEASim simulation IDAE (2011)

	Del edificio completo	Vivienda tipo (100 m²)	Puntuación
Consumo energético de fabricación de materiales	82,495 kWh	26,989 kWh	7.18
Consumo energético del edificio durante su vida útil (50 años)	187,355,525 kWh	61,295,402 kWh	4.45
Emisiones de CO2 durante su vida útil (50 años)	477,894 Kg CO2	156,348 Kg CO2	4.30

Fig. 9 Environmental assessment of the existing building/refurbished building

3.4.4 Social Assessment

The social impact was quantified from a set of indicators, such as the building's life cycle, that related to retrofitting tasks.

- I7, thermal behavior of the building during its use phase; i.e., improved temperature after refurbishing the building, reducing the energy demand from the initial state, DTi, to the retrofitted state, DTr.
- I8, eviction or interference caused by tasks performed during the rehabilitation phase, such as tasks done outside, tasks done inside and tasks that produce eviction.
- I9, duration of the retrofitting tasks, quantified by taking into account the total area refurbished, STreh and labor hours per square meter, Tobra, as mandated by the Construction Prices Database of the Government of Extremadura (2012).

Table 3 shows the method used to calculate social indicators, and Fig. 10 provides the results obtained for a use case.

Table 3 Social indicators

Social impacts			
Indicators	I7, building thermal behavior (kWh/m^2)	I8, eviction or interference	I9, duration of retrofitting tasks (h)
Calculation methodology	[(DTi-DTr)/DTi]·100	Level 1: outside tasks Level 2: inside tasks Level 3: tasks that produce eviction	Streh·Tobra
Sources	EDEASim simulation	Own reports	Prices database of the Government of Extremadura

	Del edificio completo	Vivienda tipo (100 m²)	Puntuación
Comportamiento térmico del edificio	49.30 %	49.30 %	6.16
Interferencia o desalojo	Obras interior vivienda	Obras interior vivienda	5
Duración de las obras	1,334 h	436 h	10.00

Fig. 10 Social assessment of the existing building/refurbished building

4 Conclusions

Within the framework of the European projects EDEA and E4R Renov, an analysis of the information needed to assess the energy saving potential for existing buildings was done. Upon completion of the analysis, a methodology was developed to generate the digital model produced from cadastral information, and a database of construction systems, facilities and refurbishment strategies.

This methodology was implemented into a tool called EDEASim, which main objective is to provide home or building owners with a potential energy saving estimation through refurbishment strategies (EDEASim 2015).

The web tool allowed the analyzed digital building model to be generated for subsequent simulation by the prestigious Energy + calculation engine.

The various retrofitting strategies were analyzed with different criteria: energy (saving energy), economic (cost of investment and payback period), environmental (reducing CO_2 emissions) and social (level of intrusiveness of works and their duration.

A simple and reliable tool was obtained to boost rehabilitation within Spain's energy sector.

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Adapting Buildings to the Current CTE-DB-HE: A Single-Family Housing Development in Logroño (La Rioja)

Luis M. López-González, César García-Lozano, Jesús Las-Heras-Casas and Luis María López-Ochoa

Abstract The main innovation introduced by the new CTE-DB-HE 2013 regulation for private residential housing is the mandatory limitation of energy demand and non-renewable energy consumption; such buildings, therefore, need to be simulated with official or authorised computer tools. The previous CTE-DB-HE 2009 limited energy demand, but the resulting energy demand figures were far higher than those stipulated by the current Code. A decrease in energy demand translates into final energy savings. If more efficient technologies are used, those savings can be increased. Overarching priorities include the following: a proportion of the energy used must come from renewable sources, and consumption of primary energy and CO_2 emissions must be reduced. A study has been conducted on how these parameters are affected by five different building envelopes used in single-family housing developments in Logroño (La Rioja), considering prior and current regulations. The thermal transmittance figures utilised in the study are as follows: the limit values established under the CTE-DB-HE1 2009; compliant with the CTE-DB-HE 2009; the limit values established under the CTE-DB-HE1 2013; the recommended values listed in Appendix E of the CTE-DB-HE1 2013; and compliant with the current CTE-DB-HE 2013.

Keywords Technical Building Code · Energy savings · Sustainability · Thermal envelope · Thermal insulation · Heating and domestic hot water

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1 Introduction

The main new feature of the new Spanish Technical Building Code (CTE-DB-HE 2013 (Spanish Ministry of Development 2013)) for private homes is that limits are set on energy demand and on primary energy consumption from non-renewables. This means that building simulations need to be run using official or authorised computer tools.

The previous CTE-DB-HE 2009 (Spanish Ministry of Housing 2006, 2009) limited energy demand simply by stipulating that the thermal transmittance of building envelopes should not exceed certain limit levels. The energy demand levels that resulted were far higher than those required under the current Code.

Under the current CTE-DB-HE 2013 (Spanish Ministry of Development 2013), energy demand for heating in private homes must not exceed a value, $D_{cal,lim}$, obtained from the following equation:

$$D_{cal,lim} = D_{cal,base} + F_{cal,sup}/S \quad (1)$$

where:

- $D_{cal,lim}$ is the limit set on energy demand for heating, considering the useful surface area of the living spaces, in kWh/m^2 year.
- $D_{cal,base}$ is the base value of energy demand for heating a building in each winter climate zone, in kWh/m^2 year.
- $F_{cal,sup}$ is the correction factor for surface area of the energy demand for heating, in kWh/year.
- S is the useful surface area of the living spaces in the building, in m^2.

Energy demand for cooling in summer must not exceed $D_{ref,lim}$ = 15 kWh/m^2 year for summer climate zones 1, 2 and 3, or $D_{ref,lim}$ = 20 kWh/m^2 year for summer climate zone 4.

Moreover, consumption of primary energy obtained from non-renewable sources in private homes must not exceed a value, $C_{ep,lim}$, obtained from the following equation:

$$C_{ep,lim} = C_{ep,base} + F_{ep,sup}/S \quad (2)$$

where:

- $C_{ep,lim}$ is the limit set on consumption of primary energy from non-renewable sources for heating, cooling and domestic hot water services, considering the useful surface area of the living spaces, in kWh/m^2 year.
- $C_{ep,base}$ is the base value of consumption of non-renewable primary energy depending on the winter climate zone of the area where the building is located, in kWh/m^2 year.
- $F_{ep,sup}$ is a correction factor for surface area of the consumption of non-renewable primary energy, in kWh/year.
- S is the useful surface area of the living spaces in the building, in m^2.

2 Goals

To study the variation in energy demand, consumption of non-renewable primary energy and CO_2 emissions for 5 thermal envelopes in a standard dwelling type at a single-family housing development in Logroño (La Rioja). The cases studied are the following:

- Case I: Thermal transmittance at the limit levels established under the CTE-DB-HE1 2009 (Spanish Ministry of Housing 2006, 2009).
- Case II: Thermal transmittance at levels compliant with the CTE-DB-HE 2009 (Spanish Ministry of Housing 2006, 2009).
- Case III: Thermal transmittance at the limit levels established under the CTE-DB-HE1 2013 (Spanish Ministry of Development 2013).
- Case IV: Thermal transmittance at the guideline levels recommended in Appendix E of the CTE-DB-HE1 2013 (Spanish Ministry of Development 2013).
- Case V: Thermal transmittance at levels compliant with the current CTE-DB-HE 2013 (Spanish Ministry of Development 2013).

A theoretical assessment is also drawn up of the difference between natural gas and biomass-fired boilers for producing heating and domestic hot water, with performances of 92 and 98%.

3 Method

In all five cases of thermal transmittance considered, two boilers are compared: one fired by natural gas and the other by biomass, in an average market situation. The transmittance levels are shown in Table 1.

The solar factor for openings is taken to be 0.5.

Initially, a model of the building was constructed using the LIDER IT tool, and it was confirmed that the building met the requirements, i.e. that the transmittance levels from the envelope were lower than those from the reference building

Table 1 Thermal transmittance levels used in the different cases, in W/m^2 K

Thermal transmittance	Case I	Case II	Case III	Case IV	Case V
Façades and outer walls in contact with the ground	0.86	0.66	0.60	0.27	0.25
Floors (slabs in contact with the outside air)	0.64	0.49	0.40	0.34	0.30
Roofs	0.49	0.38	0.40	0.22	0.15
Dividing walls	1.00	1.00	0.85	0.85	0.55
Interior partition walls	1.00	1.00	0.85	0.85	0.55
Openings	3.50	2.50	2.50	1.40	1.30

Table 2 Conversion factors from final energy to total primary energy, to non-renewable primary energy and to CO_2 emissions

Source	Conversion factor from final energy to		
	Total primary energy	Non-renewable primary energy	CO_2 emissions ($kgCO_2/kWh$)
Electricity	2.603	2.603	0.649
Natural gas	1.011	1.011	0.204
Densified biomass (pellets)	1.000	0.085	0.000

envelope (Appendix D of the CTE-DB-HE1 2013 (Spanish Ministry of Development 2013)) and that there was no surface or interstitial condensation. The energy demand for heating in the building under study as a percentage of the energy demand in the reference building, the energy demand for cooling in the building under study as a percentage of that in the reference building and the relative proportions between the two were also determined.

Subsequently, the CALENER VYP IT tool was used to introduce the demand for domestic hot water, with a default natural gas-fired boiler with a rated power of 10 kW and a nominal performance of 92%, and the energy demands for heating and cooling were obtained.

For this study, the demand for domestic hot water in compliance with the CTE-DB-HE4 2013 (Spanish Ministry of Development 2013) was calculated.

The following equation is used to assess final energy consumption:

$$FEC = ED/\eta \tag{3}$$

where:

- FEC is final energy consumption, in kWh/m^2 year.
- ED is energy demand, in kWh/m^2 year.
- η is the performance of the system used.

The primary energy consumption, the percentage of non-renewable primary energy consumption and the amount of CO_2 emissions can be obtained by using the conversion factors shown in Table 2.

4 Homes Studied

The building studied (Fig. 1) is a semi detached single-family home comprising ground, first and attic floors. The main façade faces north and the east wall is the division with the other, similar semi-detached home.

The ground floor contains the garage, a toilet, a multi-purpose room, utility rooms and the main entrance.

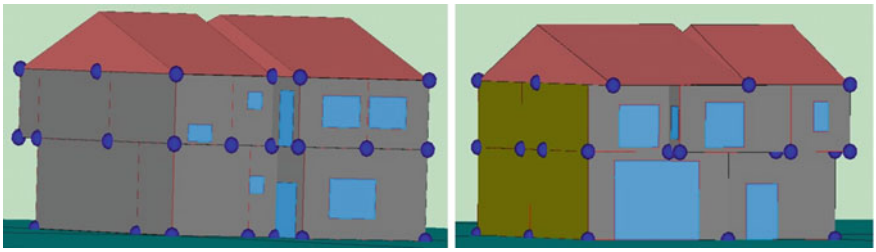

Fig. 1 3-D model in LIDER of the home studied

The first floor contains the bedrooms, bathrooms and toilets, the kitchen and a lounge diner. There is also an exterior terraced area accessible from one of the bedrooms.

The attic floor is used as a storage area.

Table 3 shows the classification of the spaces within the home.

In the inhabitable areas the internal load is low. They all feature class 3 humidity levels except for the laundry room, which is class 4.

The total surface area of the home is 262.59 m^2, with an inhabitable area of 132 m^2.

Logroño is located in climate zone D2, so for compliance with the current CTE-DB-HE1 2013 (Spanish Ministry of Development 2013) the following levels must not be exceeded:

Table 3 Classification of spaces within the home

Floor	Space	Inhabitable spaces	Non-inhabitable spaces	Humidity
Ground	Multi-purpose	x		3
	Garage		x	–
	Toilet	x		3
	Entrance		x	–
	Storage area		x	–
First	Stairwell		x	–
	Hall & passage	x		3
	Toilet	x		3
	Bathroom	x		3
	Kitchen	x		3
	Laundry room	x		4
	Lounge diner	x		3
	Terrace		x	–
	Bedroom 1	x		3
	Bedroom 2	x		3
	Bedroom 3	x		3
Attic	Storage area		x	–

- Limit of energy demand for heating: 42.10 kWh/m^2 year.
- Limit of energy demand for cooling: 15.00 kWh/m^2 year.

Under the current CTE-DB-HE0 2013 (Spanish Ministry of Development 2013) the limit for non-renewable primary energy consumption is 82.65 kWh/m^2 year.

Moreover, under the CTE-DB-HE4 2013 (Spanish Ministry of Development 2013), the demand for domestic hot water in the home and the fact that it is in solar climate zone III means that the minimum contribution of solar energy to domestic hot water is 40%.

5 Results

First of all, the figures for energy demand for heating and hot water assessed in each case are presented.

Then final energy consumption, primary energy consumption, non-renewable primary energy consumption and CO_2 emissions for heating and hot water are calculated for each of the five cases, using natural gas boilers with performances of 92 and 98% and biomass boilers with the same performances. In all cases the contribution of solar energy to hot water production is taken as 40%.

When natural gas is used as fuel, the primary energy consumption is 100% non-renewable, so the figure for non-renewable primary energy consumption is the same as that for primary energy consumption per se.

5.1 Energy Demand

The energy demands in the different cases are shown in Table 4 and Fig. 2.

5.2 Natural Gas-Fired Boilers

Table 5 shows the final energy consumption, primary energy consumption and CO_2 emissions for a natural gas-fired boiler with an average performance of 92%.

Figure 3 shows the non-renewable primary energy consumption for heating and hot water with the same boiler.

Table 4 Energy demands for heating and hot water in the building, in kWh/m^2 year

	Case I	Case II	Case III	Case IV	Case V
Energy demand for heating	73.2	62.4	60.0	42.9	39.1
Energy demand for hot water	13.5	13.5	13.5	13.5	13.5
Total energy demand	86.7	75.9	73.5	56.4	52.6

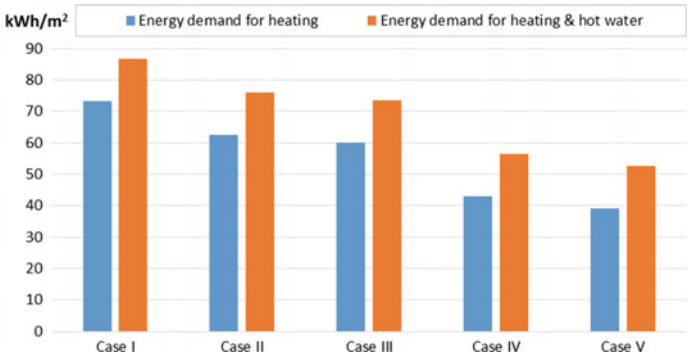

Fig. 2 Energy demand for heating and hot water in the building, in kWh/m^2 year

Table 5 Final energy consumption, primary energy consumption, in kWh/m^2 year, and CO_2 emissions, in kgCO_2/m^2 year, for a natural gas-fired boiler with a performance of 92%

	Case I	Case II	Case III	Case IV	Case V
Final energy consumption for heating	79.6	67.8	65.2	46.6	42.5
Final energy consumption for hot water	8.8	8.8	8.8	8.8	8.8
Total final energy consumption	88.4	76.6	74.0	55.4	51.3
Primary energy consumption for heating	80.4	68.6	65.9	47.1	43.0
Primary energy consumption for hot water	8.9	8.9	8.9	8.9	8.9
Total primary energy consumption	89.3	77.5	74.8	56.0	51.9
CO_2 emissions from heating	16.2	13.8	13.3	9.5	8.7
CO_2 emissions from hot water	1.8	1.8	1.8	1.8	1.8
Total CO_2 emissions	18.0	15.6	15.1	11.3	10.5

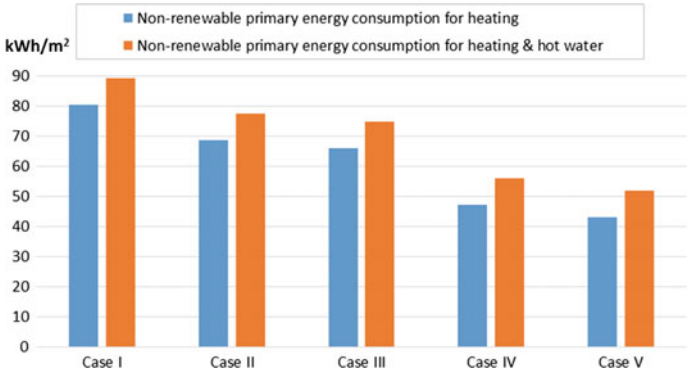

Fig. 3 Non-renewable primary energy consumption for heating and hot water for a natural gas-fired boiler with a performance of 92%, in kWh/m^2 year

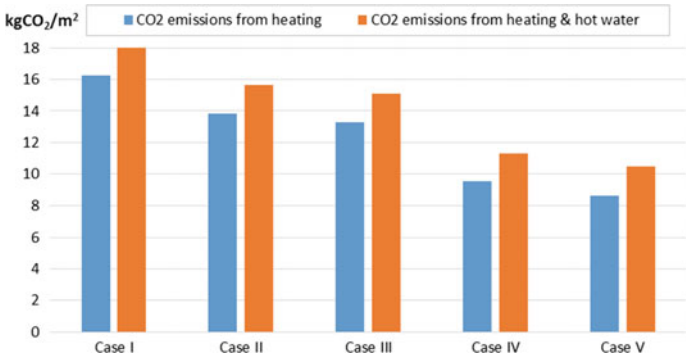

Fig. 4 CO_2 emissions from heating and hot water for a natural gas-fired boiler with a performance of 92%, in $kgCO_2/m^2$ year

Table 6 Final energy consumption, primary energy consumption, in kWh/m^2 year, and CO_2 emissions, in $kgCO_2/m^2$ year, for a natural gas-fired boiler with a performance of 98%

	Case I	Case II	Case III	Case IV	Case V
Final energy consumption for heating	74.7	63.7	61.2	43.8	39.9
Final energy consumption for hot water	8.3	8.3	8.3	8.3	8.3
Total final energy consumption	83.0	71.9	69.5	52.0	48.2
Primary energy consumption for heating	75.5	64.4	61.9	44.3	40.3
Primary energy consumption for hot water	8.4	8.4	8.4	8.4	8.4
Total primary energy consumption	83.9	72.7	70.3	52.6	48.7
CO_2 emissions from heating	15.2	13.0	12.5	8.9	8.1
CO_2 emissions from hot water	1.7	1.7	1.7	1.7	1.7
Total CO_2 emissions	16.9	14.7	14.2	10.6	9.8

Figure 4 shows the CO_2 emissions from heating and hot water for the same boiler.

Table 6 shows the final energy consumption, primary energy consumption and CO_2 emissions for a natural gas-fired boiler with a performance of 98%.

Figure 5 shows the non-renewable primary energy consumption for heating and hot water with the same boiler.

Figure 6 shows the CO_2 emissions from heating and hot water production with the same boiler.

5.3 Biomass-Fired Boilers

Table 7 shows the final energy consumption, primary energy consumption, non-renewable primary energy consumption and CO_2 emissions for biomass-fired boiler with an average performance of 92%.

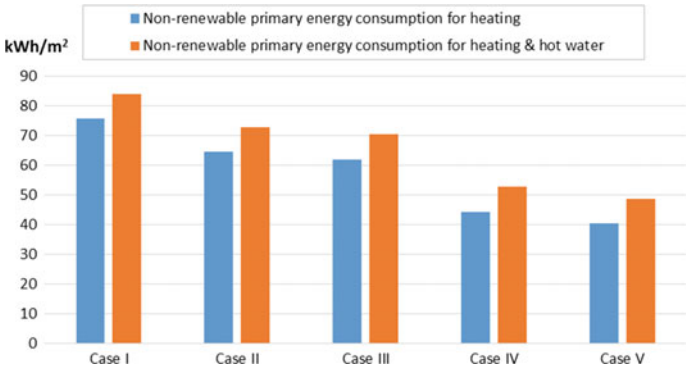

Fig. 5 Non-renewable primary energy consumption for heating and hot water for a natural gas-fired boiler with a performance of 98%, in kWh/m^2 year

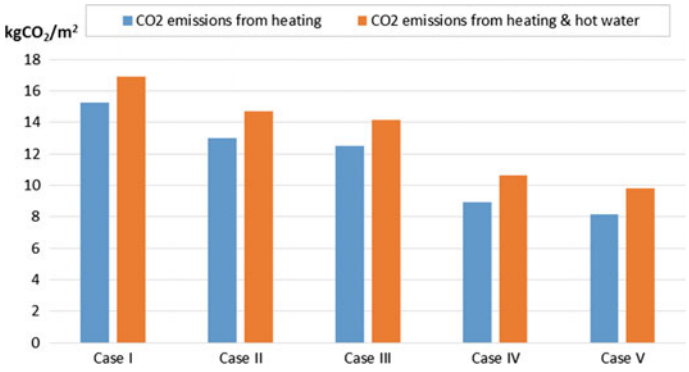

Fig. 6 CO_2 emissions from heating and hot water for a natural gas-fired boiler with a performance of 98%, in kgCO_2/m^2 year

Figure 7 shows the non-renewable primary energy consumption for heating and hot water with the same boiler.

Table 8 shows the final energy consumption, primary energy consumption, non-renewable primary energy consumption and emissions for a biomass-fired boiler with an average performance of 98%.

Figure 8 shows the non-renewable primary energy consumption for heating and hot water with the same boiler.

5.4 Analysis of Results

Of the cases studied, only Case V complies with the current CTE-DB-HE 2013 (Spanish Ministry of Development 2013).

Table 7 Final energy consumption, primary energy consumption, non-renewable primary energy consumption, in kWh/m^2 year, and CO_2 emissions, in kgCO_2/m^2 year, for biomass-fired boiler with a performance of 92%

	Case I	Case II	Case III	Case IV	Case V
Final energy consumption for heating	79.6	67.8	65.2	46.6	42.5
Final energy consumption for hot water	8.8	8.8	8.8	8.8	8.8
Total final energy consumption	88.4	76.6	74.0	55.4	51.3
Primary energy consumption for heating	79.6	67.8	65.2	46.6	42.5
Primary energy consumption for hot water	8.8	8.8	8.8	8.8	8.8
Total primary energy consumption	88.4	76.6	74.0	55.4	51.3
Non-renewable primary energy consumption for heating	6.8	5.8	5.5	4.0	3.6
Non-renewable primary energy consumption for hot water	0.7	0.7	0.7	0.7	0.7
Total non-renewable primary energy consumption	7.5	6.5	6.3	4.7	4.4
CO_2 emissions from heating	0.0	0.0	0.0	0.0	0.0
CO_2 emissions from hot water	0.0	0.0	0.0	0.0	0.0
Total CO_2 emissions	0.0	0.0	0.0	0.0	0.0

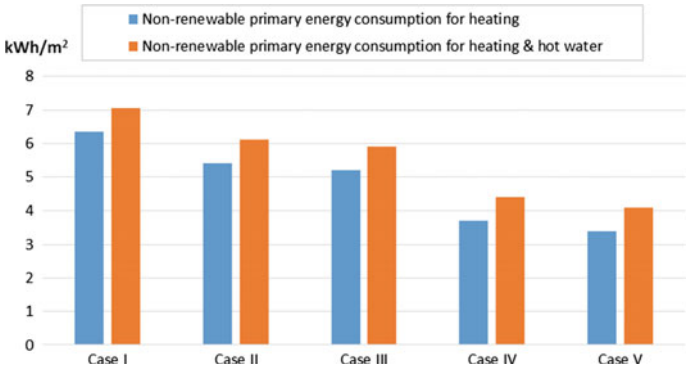

Fig. 7 Non-renewable primary energy consumption for heating and hot water for a biomass-fired boiler with a performance of 92%, in kWh/m^2 year

Transmittance via façades and outer walls in contact with the ground needs to be reduced by 70.93% on the levels in Case I. Thermal transmittance from floors (slabs in contact with the outside air) needs to be reduced by 53.13% in Case I. Thermal transmittance via roofs needs to be reduced by 69.39% in Case I. Thermal transmittance via dividing walls and interior partition walls needs to be reduced by 45.00% in Case I. Thermal transmittance via openings needs to be reduced by 62.86% in Case I.

With the outer walls used in Case V, the total energy demand is 39.33% lower than in Case I. The non-renewable primary energy consumption is 41.88% lower in the case of natural gas and 41.33% in the case of biomass with a boiler performance of 92%.

Table 8 Final energy consumption, primary energy consumption, non-renewable primary energy consumption, in kWh/m^2 year, and CO_2 emissions, in kgCO_2/m^2 year, for a biomass-fired boiler with a performance of 98%

	Case I	Case II	Case III	Case IV	Case V
Final energy consumption for heating	74.7	63.7	61.2	43.8	39.9
Final energy consumption for hot water	8.3	8.3	8.3	8.3	8.3
Total final energy consumption	83.0	71.9	69.5	52.0	48.2
Primary energy consumption for heating	74.7	63.7	61.2	43.8	39.9
Primary energy consumption for hot water	8.3	8.3	8.3	8.3	8.3
Total primary energy consumption	83.0	71.9	69.5	52.0	48.2
Non-renewable primary energy consumption for heating	6.3	5.4	5.2	3.7	3.4
Non-renewable primary energy consumption for hot water	0.7	0.7	0.7	0.7	0.7
Total non-renewable primary energy consumption	7.1	6.1	5.9	4.4	4.1
CO_2 emissions from heating	0.0	0.0	0.0	0.0	0.0
CO_2 emissions from hot water	0.0	0.0	0.0	0.0	0.0
Total CO_2 emissions	0.0	0.0	0.0	0.0	0.0

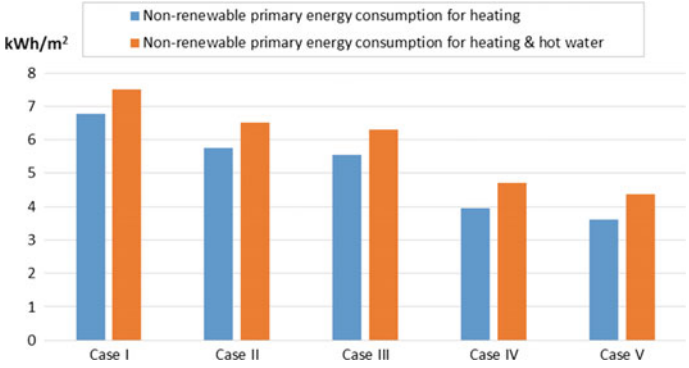

Fig. 8 Non-renewable primary energy consumption for heating and hot water for a biomass-fired boiler with a performance of 98%, in kWh/m^2 year

The outer walls used in Case V also result in CO_2 emissions 41.67% lower than in Case I for a boiler with a performance of 92%. When a biomass-fired boiler is considered, the CO_2 emissions are zero for all boiler performances and types of outer wall.

Non-renewable primary energy consumption is 91.60% lower with biomass than with natural gas for a boiler with a performance of 92%, considering the outer walls in Case I. For the outer walls in Case V, the equivalent decrease in non-renewable primary energy consumption is 91.52%. With the outer walls in Case V

non-renewable primary energy consumption is 41.95% lower than in Case I for natural gas and 42.25% lower for biomass with a boiler performance of 98%.

For natural gas, CO_2 emissions with a boiler performance of 98% are 42.01% lower for the outer walls used in Case I than for those in Case V. When a biomass-fired boiler is considered, the CO_2 emissions are zero for all boiler performances and types of outer wall.

The non-renewable primary energy consumption is 91.54% lower with biomass than with natural gas for a boiler with a performance of 98%, considering the outer walls in Case I. For the outer walls in Case V, the equivalent decrease is 91.58%.

In a biomass-fired boiler with a performance of 98% and considering the outer walls in Case V, non-renewable primary energy consumption is 95.41% lower than for a natural gas-fired boiler, with a performance of 92% considering the outer walls in Case I.

If a biomass-fired boiler is used, there are no CO_2 emissions. This is an additional advantage when it comes to assessing the average cost per ton equivalent of these emissions.

6 Conclusions

Lower energy demand results in savings in final energy consumption. Such savings can be increased with the use of more efficient technologies. The desired outcome is always for part of the energy used to come from renewable sources, and for reductions to be achieved in both primary energy consumption and CO_2 emissions.

Such actions can make a highly positive contribution to meet by 2020, the set of European targets known as 20-20-20 (European Commission 2010) in the residential sector.

As expected, Case V is the only one of the cases studied that complies with the current CTE-DB-HE 2013 (Spanish Ministry of Development 2013), which is much more stringent than its predecessors.

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Geographic Information System for Optimization and Integration of Photovoltaic Solar Energy in Agricultural Areas with Energy Deficiency and Water Scarcity

Álvaro Rubio-Aliaga, M. Socorro García-Cascales, Ángel Molina-García and Juan M. Sánchez-Lozano

Abstract The high cost of fossil fuels and the energy dependence of agriculture, primarily for use in irrigation groundwater, has been a serious challenge to agriculture in Spain. Other factors, such as the shortage of rainfall in the Mediterranean climate, increase the problem of water scarcity for farming in these areas. In response to this scenario, a sustainable development in rural areas is necessary, seeking to optimize the water and energy resources. As a useful tool to optimize and analyze natural resources, Geographic Information Systems (GIS) are proposed. GIS allow to provide crucial information, both physical and meteorological, of the study area and help in optimizing water resources and reducing energy consumption. Furthermore, the integration of renewable energy with GIS tools offer great potential in reducing greenhouse gas emissions (mainly CO_2). This can be seen in the paper with an example of optimization in the integration of photovoltaic solar facilities in the rural and agricultural sector through the use of GIS.

Keywords Renewable energy source (RES) · Resource optimization · Energy efficiency (EE) · Sustainable rural development · Geographic information systems (GIS)

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1 Introduction

Behind this energy crisis and as a result of a global energy model, underlie other crises associated with the rising prices of the fuels, such as the problematics of energy in agriculture. This problem is more complex than a priori expected and is much harsher in arid zones, where an evident problem of water scarcity and the need to pump groundwater exist. Concretely for this article, it is a question of an area on the Acuífero 23 that has been declared overexploited. The irrigated agriculture practiced here is at risk because of years of unsustainable extractions, inefficient irrigation methods and permissiveness regarding crops of high water needs, which have been undermining the capacity of that agricultural zone. This need for water pumping with diesel generators is a major economic burden for the farmer, providing him with an increasingly limited profit margin.

To explain this problem, it becomes necessary to address, in the first place, the world energy demand, which grew at a pace of 5% in 2010 and predictably will do so by up to one third more until 2035 according to the IEA (International Energy Agency).

This is due to the fact that new developing and densely populated countries, such as China or India try to accede to electricity. This then accelerates the demand for crude oil and its depletion and, therefore, its cost rises (Lara Coira 2007). Thus, for the year 2035 the IEA expects that the use of fossil fuels will slightly decrease, although they will continue having an important role in its global participation. The IEA also outlined several scenarios for the prospects of the behavior of the Brent barrel, as shown in Fig. 1. These increases will in turn generate cost increases in other areas, such as in electricity, in transport, in food or in industry.

Although today it seems that oil has given a respite with lower prices, economic analysts say that a combination of factors has led to this situation, as A. Gary Shilling of Bloomberg View says in the article "Get Ready for $10 Oil". Among these factors is the economic crisis that has reduced the demand, geopolitical offensive strategies of producing countries and an increase in supplies, in part, at expenses of future oil reserves. Others go further, prophesying a sudden rebound of the price effect; the downward trend may end in the second half of 2015, according to the IEA.

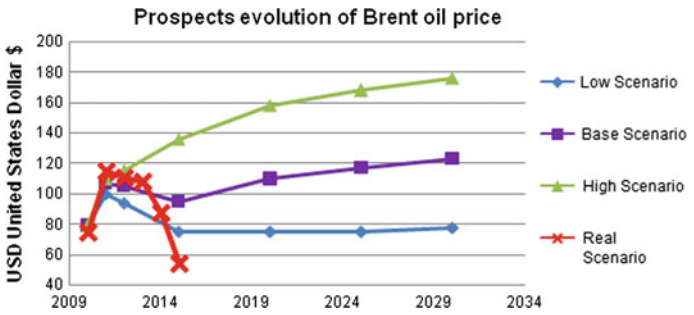

Fig. 1 Prospects evolution of Brent oil price (Boston Consulting Group, "Developments in technology and prospective costs for renewable energy technologies in 2020–2030"). *Note* Real price curve of Brent barrel until March 2015

But another protagonist appears in this current situation, the silicon. The price of the solar silicon and therefore that of the solar modules is progressively decreasing principally due to the fact that the industry has grown because of the high demand of modules, as well as the competitiveness between manufacturers (IDAE 2010). Moreover, the industrial processes in obtaining silicon and the efficiency of its production have improved substantially. This reveals the competitiveness of solar power, auguring a need to bet on it, being able to compete in price and safety of supply with the diesel equipment (Bengoetxea et al. 2006).

In this way, it becomes necessary to study the potential of the irrigation system with fossil sources to be converted to systems supported by solar power, assessing the viability of its operation. This would achieve sustainable development that respects natural resources, making it necessary to develop new sustainable energy models for change capable of generating an environmental and socio-economic benefit, either locally or at other higher levels.

The principal aim of this article is the study of the specific agricultural zone of La Mancha, with emphasis on its agricultural activity, on its aquifers, on the degree of their overexploitation, and on the socioeconomic situation of the agriculture in the above-mentioned zone. A software of Geographical Information Systems (SIG) is used to carry this out.

2 Water and Energy Problems in the Agriculture of La Mancha

The study region, La Mancha, is an extensive plain over an aquifer. There is a sedimentary basin formed by the Alpine orogeny and refilled with detrital sediments at the base, covered by alluvial mantles and "continental stuffed of Miocene and Pliocene" (García Rodríguez et al. 1996), in which the limestone karst system responsible predominates.

The area of La Mancha is, according to the Köppen-Geiger climate classification, declared as Bsk or Semiarid cold, and is determined by a continental Mediterranean climate associated with hot, dry summers reaching 43 °C, with high insolation. It has an average annual temperature "range between 14.1 and 15.3 °C" (Pérez González and Sanz Donaire 1998), where winters are cold, often below 0 °C, and a period of frost. The seasons of spring and autumn are mild and wet. Its low rainfall (300–500 mm) and very high evaporation are evidence of the arid climate, by the Martone Index, with values between 10 and 20, confirming a semiarid status.

The Mediterranean agriculture (olive tree, cereal and grapevine) has played the role of sustenance of autochthonous cultures there, as evidenced by some constructions like irrigation ditches, dams, mills, etc. It is now necessary to face up to a series of problems for the future. On the one hand, climate change predicts less rainfall, an increase in the temperature and more droughts. On the other hand, the loss of a more sustainable traditional agriculture has brought with it the abandoning of the small plots and the depopulation of large rural zones.

In Spain in general, as in this zone, there has been a marked decrease of the active agrarian population, but whereas at national level the participation of agriculture in the GDP (Gross domestic product) is very low compared to other sectors, in the study zone the agricultural sector has a very high influence in the local economy and, to a great extent, is their sustenance. The 486,296 inhabitants who live on the Acuífero 23 depend on this, including important cities such as Ciudad Real, Tomelloso, Villarrobledo, Alcázar de San Juan, Valdepeñas or Manzanares. The depopulation begins to be a problem, with a clear decline between 2013 and 2014.

2.1 Case Study

In the study area (Acuífero 23 with 5500 km^2) irrigation is an essential improvement for the agricultural production (Instituto Tecnológico Geominero de España 1989). La Mancha offers the best example of the vast dry plains that have been put in irrigation over the last century either by building dams, canals or through the banks and draining wetlands, water or the exploitation of aquifers (Bernao 2002). The water of the Acuífero 23 began to be used due to a major investment in pumping technology (Naredo 1980). During the past 40 years, the modernization of the countryside and the high production, that the large irrigation zones of well-water were contributing to, made it impossible for the traditional small farms to continue competing (economically and productively) with large plots recently put into irrigation, which were thus increasingly causing a great water strain on Acuífero 23 (Cruces de Abia et al. 1997, 1998).

Because of years and years of excessive crops (with high water demand and inefficient and incoherent irrigation technologies compared with the hydrological characteristics of the zone), unsustainable extraction coupled with poor environmental training of farmers and lack of control of the agent in charge to avoid overexploitation, caused the water table to drop dramatically (Confederación Hidrográfica del Guadiana CHG 2008). "From 1988 to 1995, which covers a period of drought and the maximum values of exploitation, with extractions of around 600 hm^3/year, the declines are accentuated reaching a mean value of 2.3 m/year" (IGME 2004). Today, there are still struggles over access to water, creating problems to reconcile agriculture with the environment (Fig. 2) (López Sanz 1993).

Today in La Mancha, they have become aware that natural resources (and the groundwater) are not inexhaustible and, also, that there is a need to regulate and take action on water management, modernizing drip and sprinkler irrigation methods, as demand and water use efficiency inevitably affect the life of the farmer (Confederación Hidrográfica del Guadiana CHG 2013; Mejías Moreno 2012).

The drop in the groundwater level is a problem difficult to support for the farmer, since it forces to take a significant share of the profits from production, to pay for the fuel to pump the necessary water to avoid spoiling the land and harvest. This causes a reduction in the profit margin for farmers, that can only increase the price of products at risk of losing out against competition with cheaper products from developing

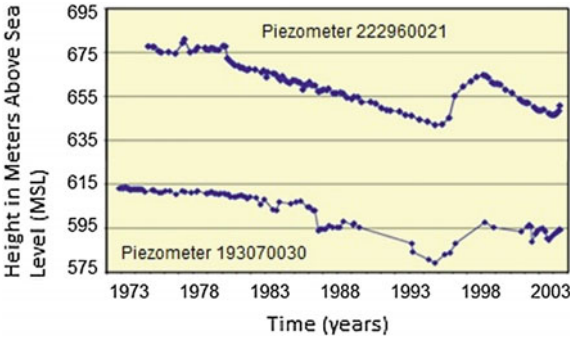

Fig. 2 Example of the descent in the water table in Acuífero 23 in two piezometers (*Instituto Geológico y Minero de España IGME*). *Note* A rapid recovery was observed between 1997 and 2000, caused principally by a humid period and some restrictions imposed in the extractions derived from overexploitation

countries, which in fact is what happens on many occasions (Lamo de Espinosa 2009). Others leave the crop or the agricultural plot, which although perfectly suitable for dry farming generates so little profit that they cannot survive on it. Thus, the small plots of 2–6 ha with a well are disappearing as it is not profitable to maintain the well, in benefit of big particular groups of 20 or more hectares.

This forces the Spanish Government to subsidize the agricultural use of fuel, necessary in order to at least support agriculture and with it the life of the farmer. According to Article 52, of the Law 38/1992 of Special Taxes, it recognizes the right to the partial return of the quotas of the Tax on Hydrocarbons to farmers and ranchers.

A rise in energy prices in the future puts those sectors that depend on oil into very serious difficulties, and this includes agriculture. This can generate a massive land abandonment in which it is not economically viable to pump irrigation water. Therefore, this shows clear evidence of how the energy problem finally emerges, conditioning the economic viability of many crops and agricultural areas, and the need to find a short term solution.

In this way, and considering the gradual integration of renewable and local resources in every zone, it becomes necessary to analyze solar power as a good tool to improve this situation and to study the potential conversion of fossil fuel irrigation systems to systems fed on solar power, valuing its viability.

3 Methodology

The GIS (which first appeared in the last 20 years) are made up graphic and alphanumeric data bases with functions of digital mapping tools. That is to say, operating with two types of information, spatial location and thematic, and they should be capable of integrating, storing, editing, analyzing and sharing data, and present the results. Therefore, GIS are tools for query, analysis, visualization and

geographic edition. Their aim is to provide solutions to problems and challenges raised in the territory, allowing to create models of evaluation, to carry out processes of simulation, to plan and to analyze the spatial reality with the intention of managing the models proposed for optimal performance on the territory, and assess the consequences of an action minimizing risks. In short, they allow "a continuous updating of information, making a dynamic GIS system" (Basildo et al. 1998). With the GIS, what is sought in this case is to determine the agricultural plots and their applicability to the solar pumping of the study zone (Sánchez-Lozano et al. 2012).

3.1 *Process of Application of the GIS to the Case Study Determination of the Agricultural Plots and the Applicability of Solar Pumping*

A methodology has been followed which sought to isolate the plots of agricultural use over the Acuífero 23 exclusively, as can be seen in Fig. 3. Thus, several blocks of maps of the zone of study are taken. A few maps or layers with descriptive

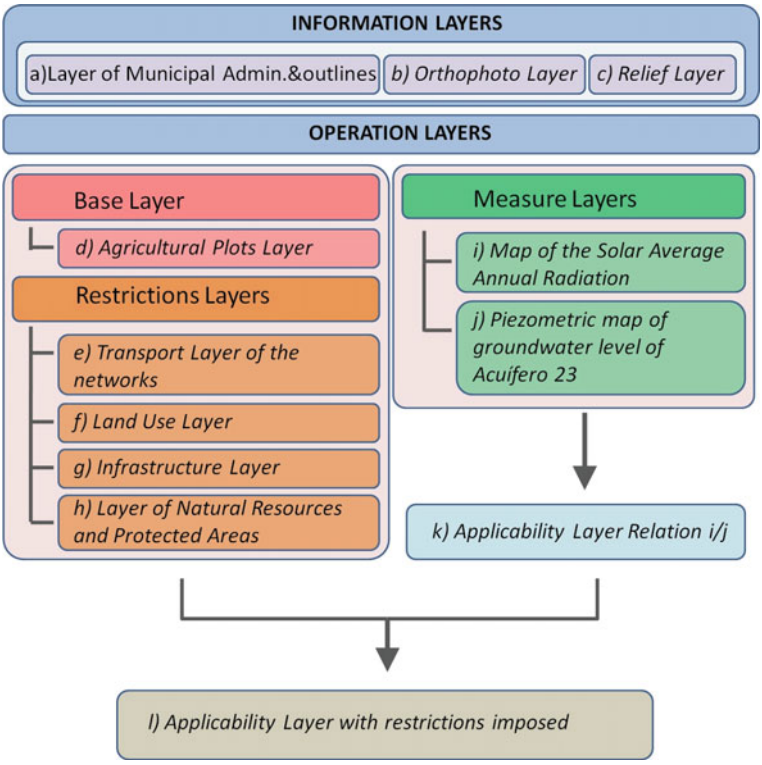

Fig. 3 Application of GIS process to case study (compiled by author)

information to frame and to locate the zone of study are: (a) Layer of Municipal Administrations and outlines, (b) Orthophoto Layer, and (c) Relief Layer.

Furthermore, the layers of operation are divided into:

- Subblock of base-layer of rustic plots over which it is working.
- Subblock of restrictions, with which elements of the base-layer are extracted that do not have an agricultural use.
- Subblock of layers of measure, among which are the map of solar radiation and the map of depth of aquifers.

Taking (d) *Agricultural Plots Layer* over the Acuífero 23 as the base a file is opened using SIG. An intense precision work was carried out on this map, eliminating the information that appears in the following layers to obtain the plots in which there is not another activity other than strictly the production of food and agricultural products of the zone (Olive grove, vineyard, cereal, vegetables, etc.).

Stage 1. The layer of restrictions was loaded and the plots, with a codification relating to some of the restrictions, were extracted by the tool "differs" or from the table of attributes. If it is a line that was to be extracted, before that it was necessary to generate a polygon with the "buffer" tool.

Stage 2. A difference has been made between (e) *Transport Layer of the networks* and (d) *Agricultural Plots Layer.*

Stage 3. After that, the difference has been established between (f) *Land Use Layer* and the Layer Resulting in the previous stage.

Stage 4. Later, the difference between the (g) *Infrastructure Layer* and the Layer Resulting in stage 3.

Stage 5. Subsequently, the difference between the (h) *Layer of Natural Resources and Protected Areas* and the resulting layer of stage 4, thus obtaining a layer with agricultural plots where there is only agricultural activity.

Stage 6. The information from the meteorological stations is applied on (i) *Map of the Solar Average Annual Radiation*, to produce a map of solar radiation of the zone.

Stage 7. The same was done with the piezometric data that was introduced into (j) *piezometric map of groundwater level of Acuífero 23* to result in a depth map.

Stage 8. The (k) *Map of the Average Annual Solar Radiation/piezometric map of groundwater level of Acuífero 23* is elaborated, thus obtaining the layer applicability in all of the Acuífero 23 (earlier restrictions have not yet been imposed to this layer).

Stage 9. Finally, the applicability layer is applied to the layer of agricultural plots, to those plots on which later restrictions will be imposed, thus obtaining the (l) *Applicability Layer with restrictions* imposed. This is a layer with rustic parcels located on the aquifer, likely to be irrigated with groundwater and hence of having an agricultural production with the restrictions imposed by the study and with the degree of applicability for solar pumping.

3.2 Layers Used

This step has sought to define the study area to the area of the Acuífero 23 in Castilla La Mancha. The 65 municipalities have part of their municipality on the Acuífero 23 and are located at the confluence of the provinces of Toledo, Cuenca, Albacete and Ciudad Real, with much of the latter province.

As soon as the study zone is known, the study and description of the area in all its characteristics that are useful for this research is performed. To do this, the layers that indicate some restrictions or provide information or guidance are listed.

(a) *Layer of Municipal Administrations and outlines*. It is a national and regional information layer. The study area and the administrations responsible for the conservation of the agriculture in the above mentioned zone can be easily located. Figure 6 in Appendix.
(b) *Orthophoto Layer*. This layer is necessary for a major description of the environment and understanding of what happens at ground level, although it does not contribute specific binding information with the final result. Figure 7 in Appendix.
(c) *Relief Layer*. With this, it seeks to provide the information relating to the orography and the altitude of the study area by using the curves of level, allowing to clearly seeing the flat terrain of this area surrounded by small elevations. Figure 8 in Appendix.
(d) *Agricultural Plots Layer*. To go deeper it was necessary to discharge through "Sede Electrónica del Catastro" some detailed maps of agricultural plots and every one of the municipalities sitting on the Acuífero 23 that irrigate their fields with groundwater. Figure 9 in Appendix.
(e) *Layer of Transport networks*. In this layer, the principal arteries destined for transport are shown—the highways appear, along with national and regional roads and different roads of minor importance such as the tracks between towns. Additionally, landing strips and means of transportation such as the train are included. For example, the high speed AVE (Alta Velocidad Española) Madrid-Seville line is included passing through Ciudad Real, as well as the conventional train. Figure 10 in Appendix.
(f) *Land Use Layer*. In this part, all the polygons are collected that refer to constructions and developments, which can be: urban, spread constructions, such as chalets or agricultural constructions. Also, in this layer it is possible to find the zones of industrial use. Other type of plots are in this layer, such as quarries or open pit mines. Figure 11 in Appendix.
(g) *Infrastructure Layer*. In this layer, the infrastructures of electrical type are indicated, such as power lines and power generation facilities that are included within the study zone, in this case, solar plants or wind farms. The distribution of fuels and gas pipelines are also indicated. Figure 12 in Appendix.
(h) *Layer of Natural Resources and Protected Areas*. In this layer, the rivers of the River Guadiana basin (Guadiana-Alto Guadiana) and its tributaries (Záncara, Córcoles, Cigüela, Azuer) are shown, as well as the channeling artificially

made (Channel of the Great Prior) and areas irrigated with surface water and the newly renovated irrigation area of "Estrecho de Peñarroya". On the other hand, it also shows the lagoons and wetlands among which the protected area Las Tablas de Daimiel must be mentioned. To these, other wetlands formed between Pedro Muñoz and Alcazar de San Juan that are the product of the outcrop of water springs, must be added, also indicating these areas of special interest and protection. Figure 13 in Appendix.

(i) *Map of the Average Annual Solar Radiation.* Through the data of 9 stations in the study area, property of the Siar of Castilla La Mancha, an agricultural organization that uses this data to assess and advise farmers in irrigation and has specialized pyranometers SKYE SP1110 (CAMPBELL), an analysis of incident solar resource in the area of the aquifer has been conducted. A detailed map of solar radiation with a GIS, distribution of radiation on the study area has been produced with annual data for each of the stations. Figure 14 in Appendix.

(j) *Piezometric map of groundwater level of Acuífero 23*. A GIS layer profile of the aquifer has been performed. The area also has information about the depth at which the aquifer is located in different parts of the study area, through information gathered from 26 piezometric stations in the Guadiana River Basin, used to keep track of that body of water and in collaboration with the Community of Irrigators of Acuífero 23. This map does not take the reference height in meters above sea level (MSL) of the groundwater level of the Acuífero 23, but its depth from the surface. Figure 15 in Appendix.

It is necessary to indicate the difficulty of drawing the outline of the Acuífero 23, since it is a dynamic water mass influenced principally by two factors: the height of the groundwater level and the geological materials that use as continent, which can be impermeable (as in the case of the Mounts of Toledo) or on the contrary be permeable (and have a very diffuse line of delimiting). Likewise, several maps delimiting the Acuífero 23 have been taken to establish its actual dimensions and to determine which of them is more adjusted to the area.

4 Results

On the one hand, the results provide the Applicability Layer, which shows an index of applicability associated with the relation between solar incidental radiation and the level of the groundwater (Fig. 4). On the other hand, the Applicability Layer with restrictions, shows the applicability of the solar power to the above-mentioned zone in the plots that remain available for a strictly agricultural use (Fig. 5).

It is evident that the results provide a wide green zone that serves to show the potential that solar power has in the above-mentioned zone. It is important to indicate that this final layer shows the degree of applicability, or differently said, the easiness with which the water would be obtained by solar pumping. As has already

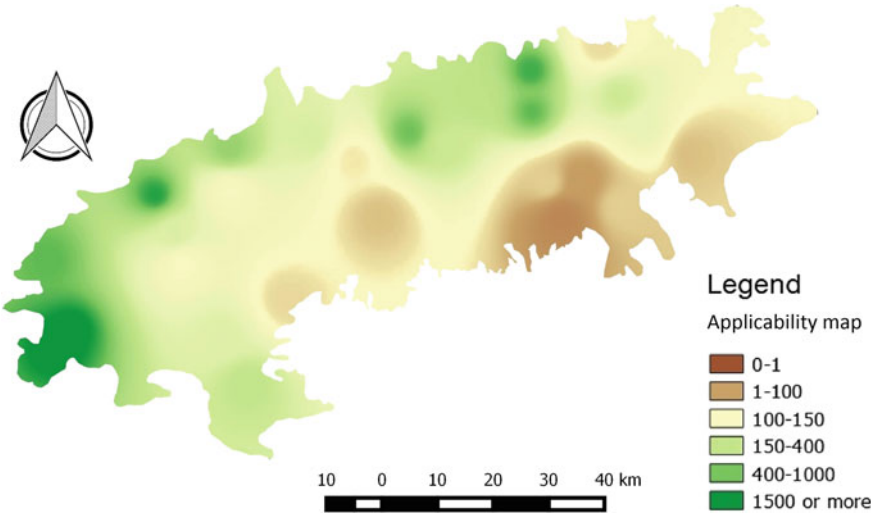

Fig. 4 Applicability layer (compiled by the author). *Note* Graduation of colors observed between the zones with higher values of the relation "Radiation/water depth" in *green* and the zones with lower values in *brown*

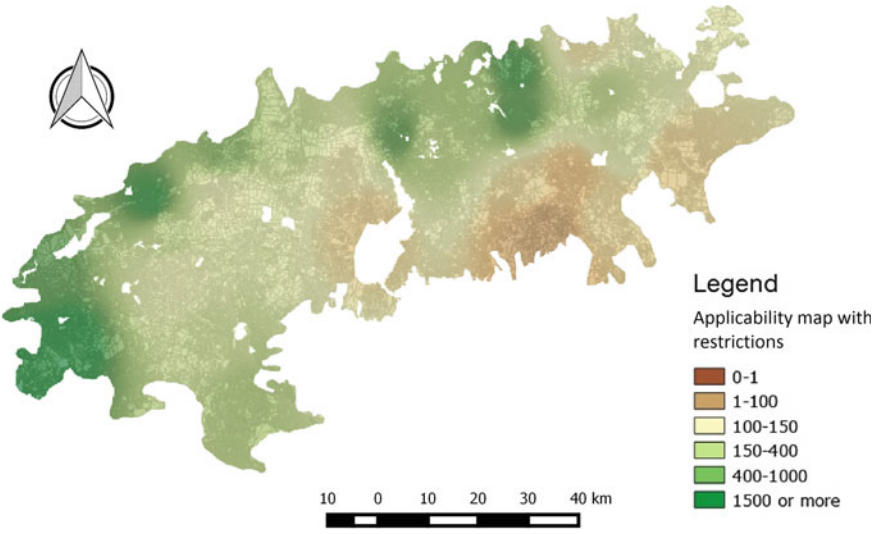

Fig. 5 Applicability layer with restrictions (compiled by the author) *Note* It is clearer with aspects already erased: cities and towns, protected zones and irrigation with superficial waters zones

been stated, this last layer indicates in what places, for the same use (irrigation of an equivalent number of hectares), the investment could be major or minor. Bearing in mind that both zones can be profitable or economically feasible, in the green tone areas as well as in the brown tone ones, it will only be necessary, hereinafter, to compare it with the current expenses of the farmers pumping with diesel.

5 Conclusions

With the present article it is possible to see how the solar power has a great future in agricultural applications. For those zones that have difficulties due to the high price of fossil fuels that needs be dedicated to groundwater pumping, and more concretely in the study area of the Acuífero 23 in Castilla La Mancha, this study has demonstrated that another way of obtaining water for agriculture is possible. It is also a milestone in modernization, with GIS programs, of the agriculture of La Mancha that satisfies its water needs from Acuífero 23.

In agreement with the aims of the article, the analysis is focused on the substitution of energy sources and the agricultural reorganization to make a more efficient use of solar power. Moreover, it is possible to generate other associated benefits in topics as important as employment, safety in agricultural facilities or water efficiency.

It is proposed as future work, the assessment of the degree of group of plots in order to create irrigation installations with ponds where the farmers could irrigate automatically, with an efficient use of water and energy. In addition, the economic, social and environmental sustainability can be studied to achieve, the above-mentioned agricultural reorganization.

Thus, it appears that the application of renewable sources for agricultural use is a field that, although it takes years to develop, still needs a lot of work to research and to apply, principally in the modernization and automation of agricultural processes and in the agricultural cooperativism in search of the common benefit.

Acknowledgements This work has been partially supported by funds, DGICYT and Junta de Andalucía under projects TIN 2014-55024-P and P11-TIC-8001, respectively.

Appendix

Layers used in the process of characterizing the applicability of solar pumping to the study area (Figs. 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15).

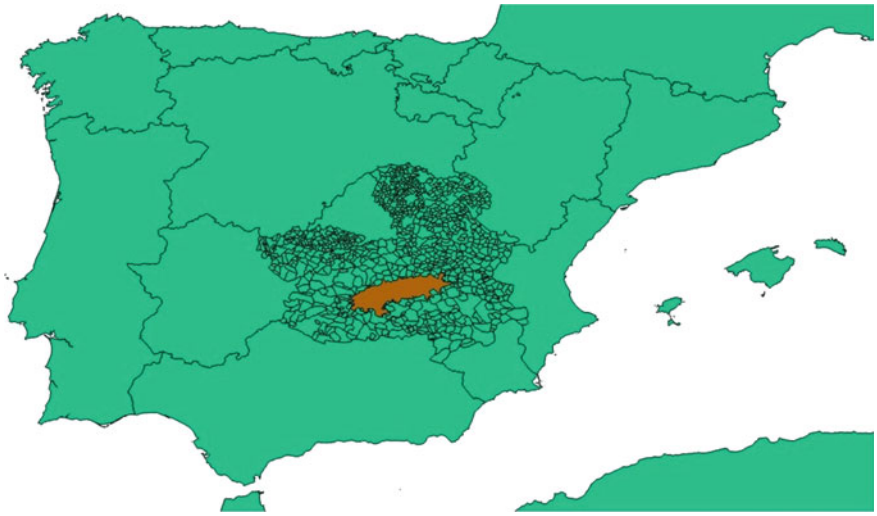

Fig. 6 Layer of municipal administrations and outlines. *Source*: National Geographic Institute (IGN)

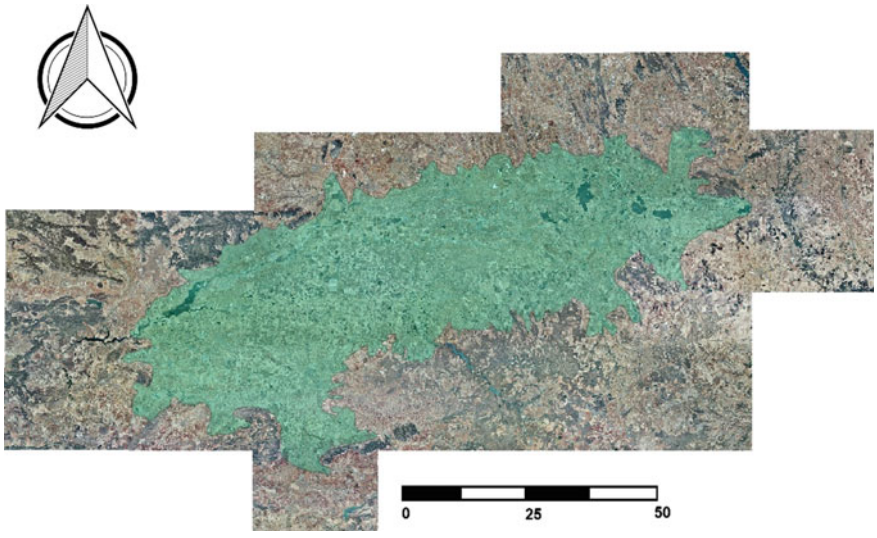

Fig. 7 Orthophoto layer. *Source*: National Geographic Institute (IGN)

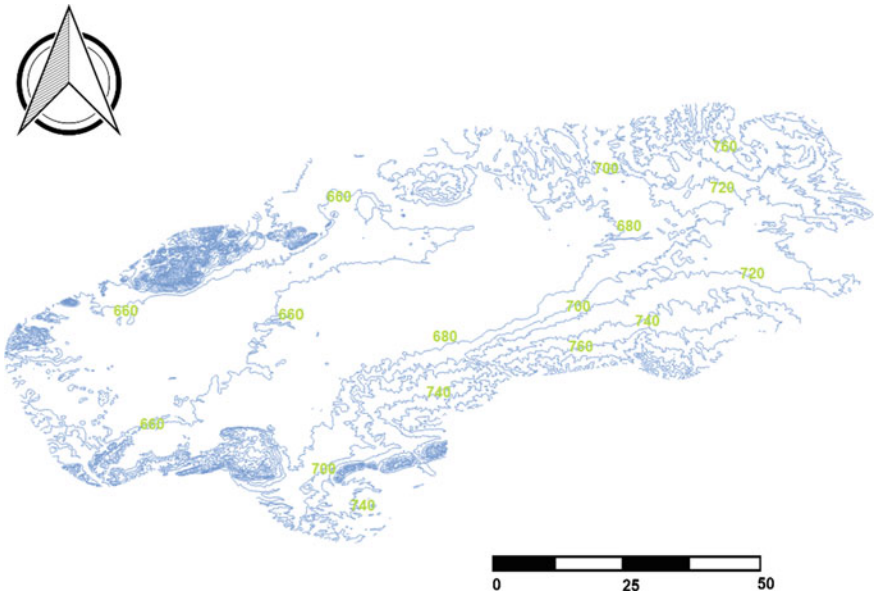

Fig. 8 Relief layer. *Source*: National Geographic Institute (IGN)

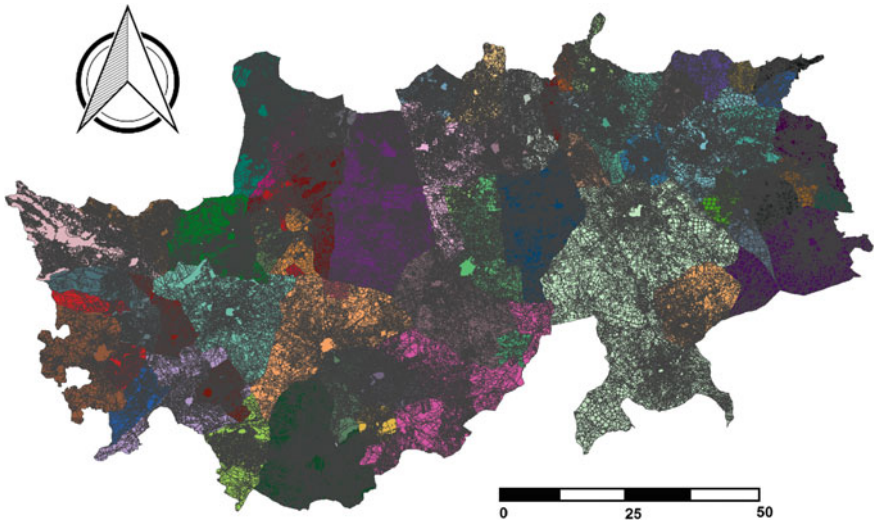

Fig. 9 Agricultural plots layer. *Source*: National Geographic Institute (IGN)

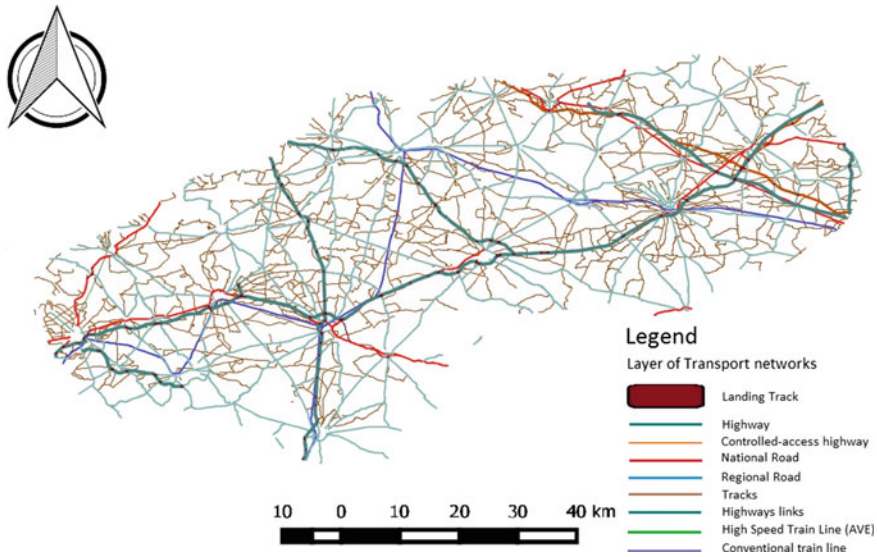

Fig. 10 Layer of transport networks.*Source*: National Geographic Institute (IGN)

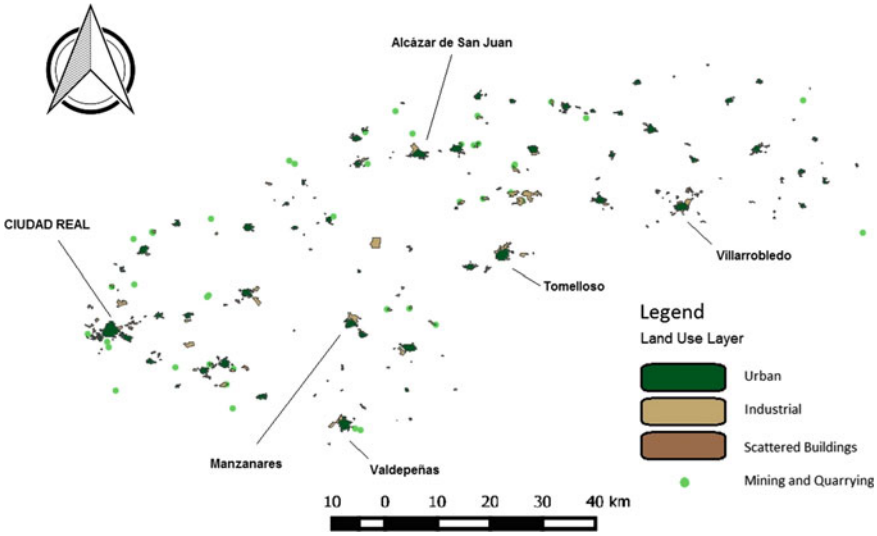

Fig. 11 Land use layer. *Source*: National Geographic Institute (IGN)

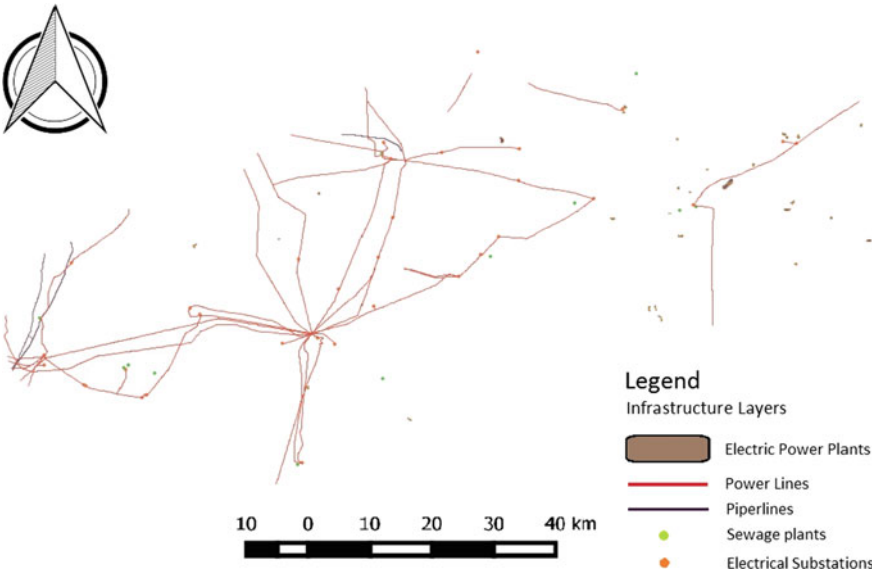

Fig. 12 Infrastructure Layer. *Source*: National Geographic Institute (IGN)

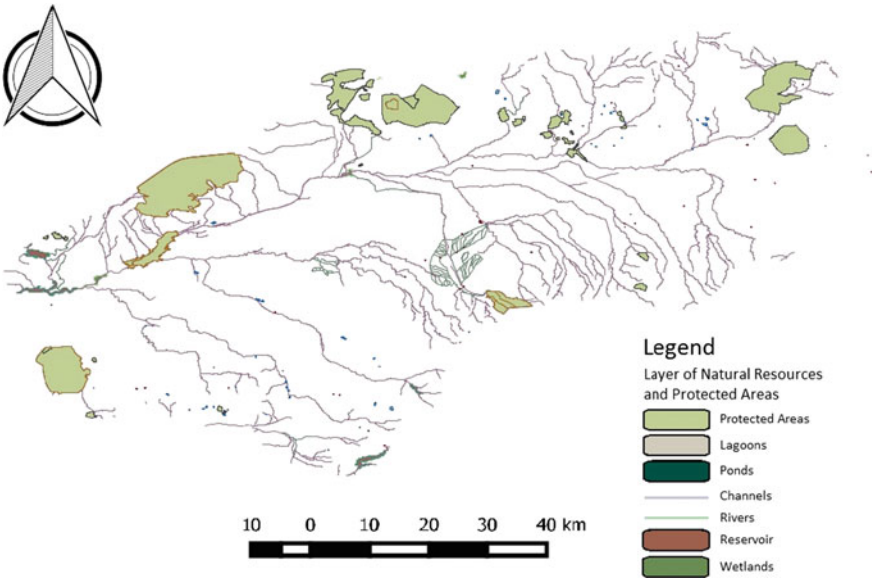

Fig. 13 Layer of natural resources and protected areas. *Source*: National Geographic Institute (IGN)

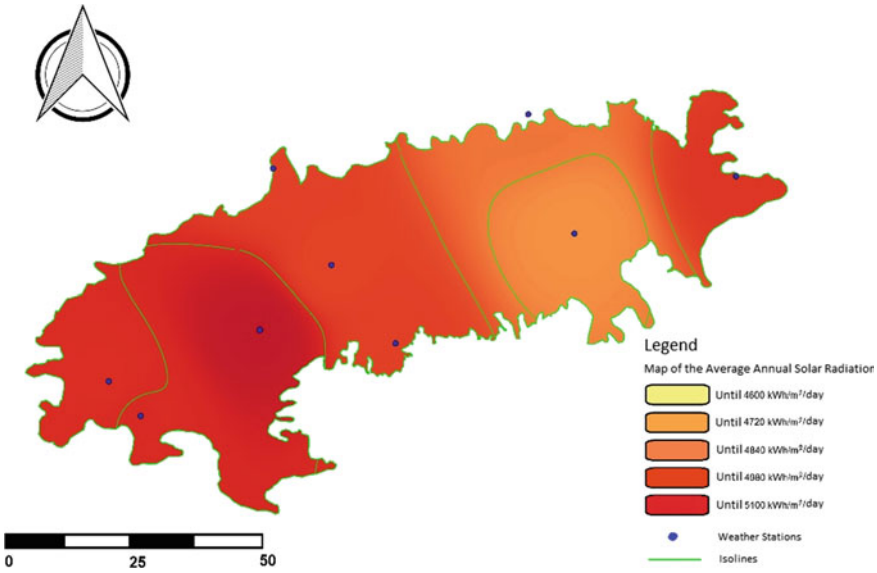

Fig. 14 Map of the average annual solar radiation. *Source*: Author's own Research

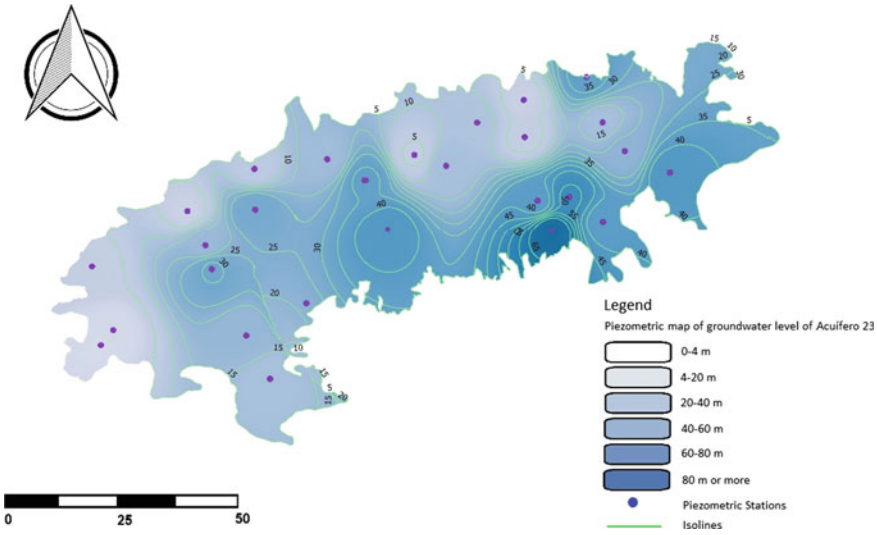

Fig. 15 Piezometric map of groundwater level of Acuifero 23. *Source*: Author's own Research

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Part VI
Rural Development and Development Co-operation Projects

RETRACTED CHAPTER: *Guadua angustifolia* as a Structural Material for Greenhouse Design

Eduardo Garzón, Manuel Cano García, Luis Pérez-Villarejo, Sergio Martínez-Martínez and Pedro José Sánchez-Soto

Abstract In Mediterranean greenhouses, wood is the most widespread structural element, although it is currently being replaced by galvanized steel. This substitution is not compatible with the change of a productive-constructive model, which seeks to leave a viable environment for the future generations by not exceeding the Earth's carrying capacity, which is one of the fundamental worries of the humanity. In this sense, the present work examines the possibilities of material application of the bamboo species guadua (*Guadua angustifolia*), considered as a valid and sustainable alternative for greenhouse design. This initiative consists of analysing the possibilities of guadua as structural material for the "parral" type greenhouse of Almería. For this characterization, it has been necessary to review the works related to the use of the above-mentioned bamboo species as a building material.

Keywords Bamboo · Material · Greenhouse · Design · Structure

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1 Introduction

The "parral" or Almería greenhouse model, originally from the province of Almería (Spain), consists of wooden beams and metal wires (called "parral") forming the support structure of the greenhouse (Fig. 1). In this model, wooden poles are vertically supported by individual foundation slabs attached to each other by tensed guy-wires running along the top. Along the perimeter, outwardly inclined poles are equally spaced providing stability to the overall structure. Tensed wires also serve as supports for the two wire networks between which a plastic film lies, in the manner of a sandwich. The lower network is made up of wires (laid out on a 30 × 30 cm or 20 × 40 cm grid) and the upper network can be made up of plastic cord (laid out on a 40 by 40 cm grid). After the film is installed, the two wire networks are secured to the tensed wire cables by thin wires that pierce the sheet and have to be snipped when the plastic film is changed (FAO 2002).

Throughout the entire range of Mediterranean greenhouse designs, wood is the most widespread structural element, while polyethylene film with various optical and mechanical properties is the prevailing roofing material. The "parral" greenhouse, together with the derivative versions of its original design, is the most common example of an indigenous greenhouse. In Almería alone, there are about 27,000 ha "parral" greenhouses and its "raspa y amagado" (sloping roof design) variant (EFSA 2009). Its construction features can be found in various studies (Pérez 1998). Since 1961, when the first "parral greenhouses" were roofed with plastic, this type of greenhouse has had a profound impact on the socio-economic development of Almería, as well as in many other countries. The "parral" greenhouse has achieved a positive cost-benefit balance, enabling the creation of small family businesses (each of which has continued to grow gradually) due to the low initial investment (Montero 2012).

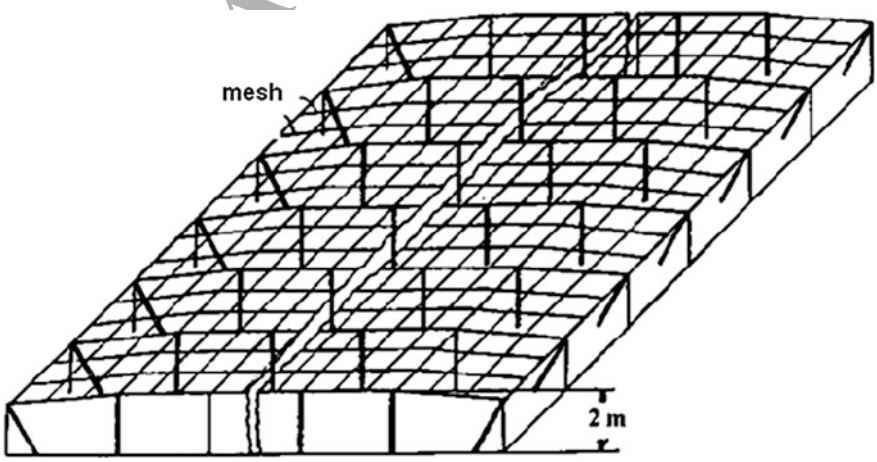

Fig. 1 Almería or "parral" greenhouse model

Its structure was originally built with wood, but it is currently being constructed more and more with galvanized steel pipes. The present study compares structural materials of the parral greenhouse, but using the bamboo species *Guadua angustifolia* Kunth (Fig. 2). Although guadua is an internationally used building material, neither ideal nor sufficient conditions exist for the production, legislation, marketing or industrialization of this raw material. In this context, the present study analyses the use of bamboo canes as a structural material in the specific construction of a "parral" greenhouse.

Although there is still no code or regulation allowing international standardization of the material, for over more than 30 years numerous tests have been made to determine the physical and mechanical properties of guadua. For the characterization of this material, it is essential to assess the loads it can withstand, in this case in the context of greenhouse design.

Most of the major research has been performed in Colombia (South America), where this bamboo is a native species. These studies date from the 1970s with the work of Merino et al. (1972), Hidalgo (1978), Carvajal et al. (1981), Trujillo and Peláez (1983), and others. Nevertheless, the results cannot be compared or analysed statistically because at that time there was no standard for evaluating the performance of the test procedures. INBAR (1999) subsequently published a manual for determining the physical and mechanical properties of bamboo, setting the basis for further research to assess the compressive strength parallel to the grain (Uribe and Durán 2002; Prada and Zambrano 2003), shear strength parallel to the grain (Acuña and Pantoja 2005), and compressive modulus of elasticity (González 2006).

The physical and mechanical properties of guadua are an expression of its performance when subjected to external forces and this performance depends on the type of force applied and the structure thereof. In general, these properties determine the suitability of wood for use in construction and in many other applications, such as crafts (Giraldo and Sabogal 1999).

Preliminary to understanding the physical and mechanical properties of this plant species, trials are undertaken in which the test conditions of Colombian timber

Fig. 2 *Guadua angustifolia* Kunth canes

standards established by the Colombian Institute of Technical Standards and Certification (ICONTEC) are reproduced and the standards of the American Society for Testing and Materials (ASTM) are followed.

2 Analysis of Test Results

For the technical and mechanical characterization of guadua, the results of the mechanical tests conducted by Arboleda et al. (1997), Aricapa et al. (1999), and González (2005) were reviewed: axial compression test, a compressive test perpendicular to the grain, a tensile test parallel to the grain, a bending test, and a shear test parallel to the grain. Figures 3, 4, 5, 6, and 7 show the arrangements and dimensions of the specimens used to perform those trials.

It is recommendable to evaluate the methods of treating guadua (drying, waterproofing, preserving) in order to determine whether these methods alter its mechanical properties. In this sense, Viitaniemi (1997), Gohar and Guyonnet (1998), Jämsä and Viitaniemi (2000), Rapp and Sailer (2000) stated that changes in the mechanical properties are the main problems caused by the heat treatment processes.

Furthermore, according to Moreno et al. (2006) studying the properties of the *Guadua angustifolia* fibre bundles (using stress tests), the values appreciably varied. In particular, because bamboo is an organic material, the tensile strength can be affected by growing conditions, the harvest process, and climatological factors.

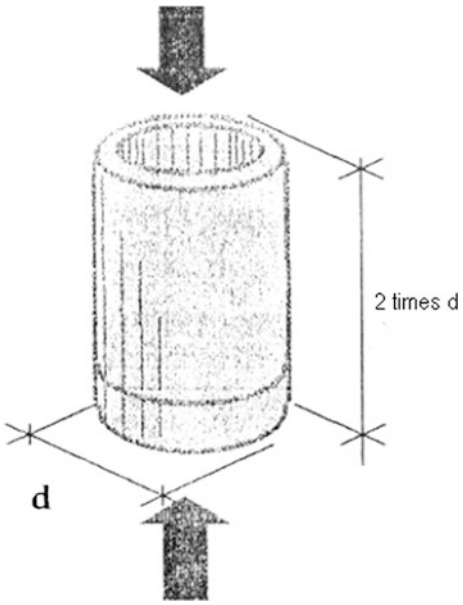

Fig. 3 Axial-compression test (González 2005)

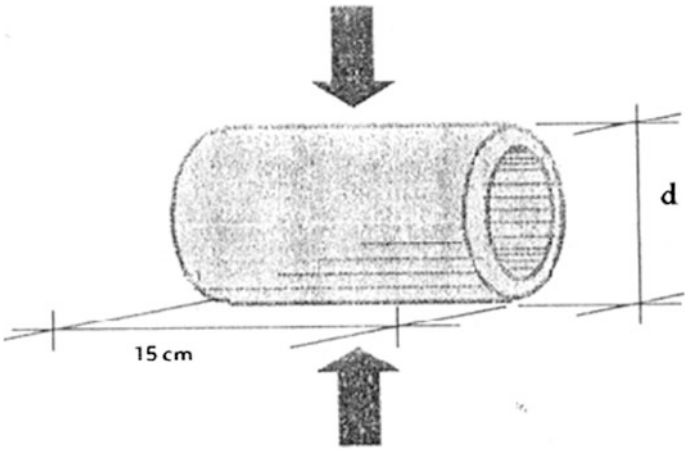

Fig. 4 Compressive test perpendicular to the grain (González 2005)

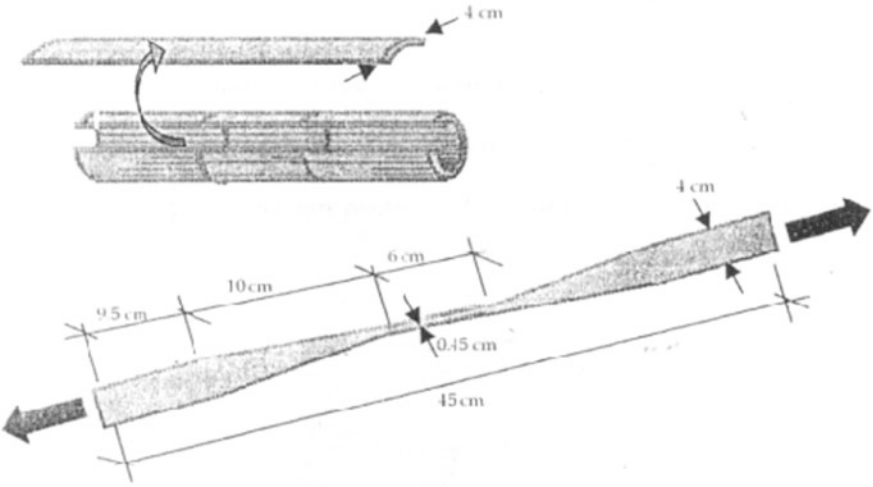

Fig. 5 Tensile test parallel to the grain (González 2005)

González (2005) outlined the implementation of a conservative design, considering the lowest values found over the last 55 years as minimum values for ultimate strength. The values proposed are listed in Table 1.

The following reduction factors in Table 2 should be applied to the values in Table 1; according to Arboleda et al. (1997), and Aricapa et al. (1999). When guadua is used as a structural material, the values of minimum ultimate strength, modified with safety factors must be used because, despite being a homogeneous material, this bamboo collapses before reaching its yield point. The board of the

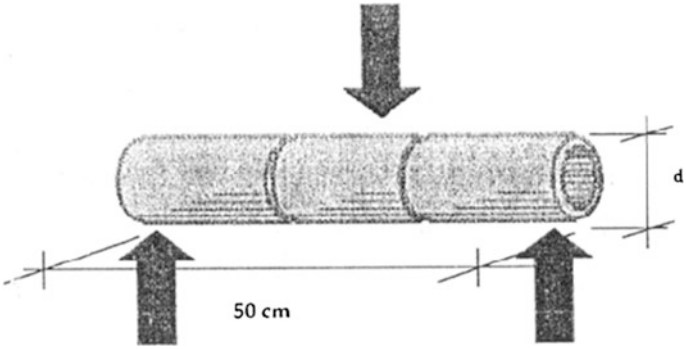

Fig. 6 Bending test specimen configuration (González 2005)

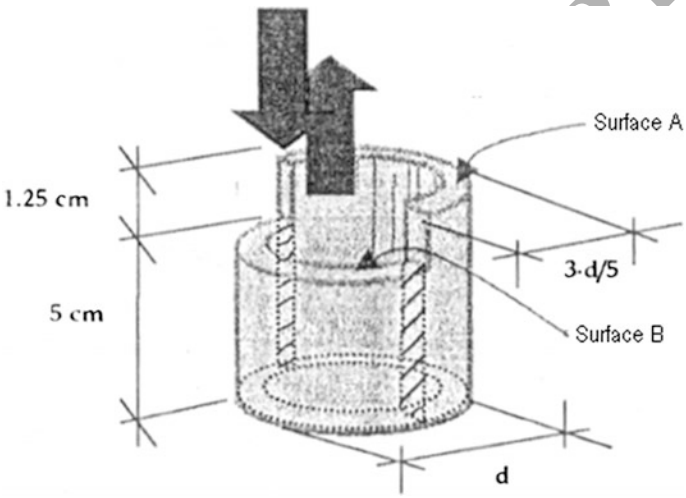

Fig. 7 Shear test parallel to the grain (González 2005)

Table 1 Results for minimum ultimate strength. Units in MPa

	FC	FT	FS	FDC	CM
Perpendicular compressive stress (Fp)	1.0	1.00	1.60	1.00	1.00
Parallel compressive stress (Fc)	1.00	1.00	1.60	1.25	1.00
Bending stress (Fb)	0.80	0.90	2.00	1.25	1.00
Parallel shear stress (Fv)	1.00	1.00	4.00	1.00	1.00

Taken and adapted from González (2005)

Table 2 Reduction factors for minimum ultimate strength. Units in MPa

Stress	Minimum ultimate strength (MPa)
Perpendicular compressive stress (Fp)	0.23
Parallel compressive stress (Fc)	17
Bending (Fb)	7
Parallel shear stress (Fv)	1.8
Perpendicular tensile stress (Ftp)	0.18
Parallel tensile stress (Ft)	50
Tensile modulus of elasticity	1500

Taken and adapted from González (2005)

Cartagena Agreement (JUNAC) (1984), established the values for the reduction factors shown in Table 2.

Finally, the allowable stress can be calculated using the following expression:

$$\sigma adm = [(FC \times FT \times CM)/(FS \times FDC)] \times \sigma i \quad (1)$$

where σadm = allowable stress (MPa), σi = minimum strength (MPa), FC is the quality-reduction factor (dimensionless), FS is the service and safety factor (dimensionless), FT is the size-reduction factor (dimensionless) FDC is the load-duration factor (dimensionless), CM is the moisture-correction factor (dimensionless).

Laude and Obermann (2003), based on the work of Martín et al. (1981), García and Martínez (1992), González and Díaz (1992), López and Trujillo (2000), and Lindemann and Steffens (2000), concluded their research with an average of minimum strength for all the results checked. This was done taking into account the different specifications and values in the samples taken (as a bamboo cane displays different physical and mechanical characteristics according to the geographical area it was taken from).

In connection with this average, to gain an estimate of how guadua performs compared to wood or steel, the present study was conducted with lengths of 3 materials, each 2.5 m long, similar sections weighing approximately 8.7 kg, all being subjected to compression. The results are shown in Table 3.

Table 3 indicates that for a section of guadua (D = 12 cm, d = 9 cm) 2.5 m long, a maximum load of 25 kN compression can be applied, implying that a load of up to about 100 kN can be applied to tensile strength. Furthermore, guadua is much stronger than wood and its relationship between maximum strength and weight gives it strength similar to that of steel. The steel section could be lengthened, but its weight and the price would increase accordingly.

Concerning this comparison, it bears noting that although guadua has a modulus of elasticity of 600 kN/cm^2, about 30-fold lower than that of steel, it can withstand a maximum allowable force of 25.6 kN, close to that of 27.6 kN for steel.

Bamboo, with its tubular shape, also provides slenderness and optimum performance of the tested section, its compression strength being ideal to prevent

Table 3 Wood-guadua-steel comparison

Compression of a length of 2.5 m and 8.7 kg of different materials	Type B wood EC5 S10/MS10		Guadua EC5		Steel, A36 EC3 S235	
Density (g/cm^3)	0.55		0.7		7.8	
E-modul. (kN/cm^2)	740		600		21,000	
Compressive forces applied (kN/cm^2)	1.1		1.5		23.5	
Section	 D = 9 cm		 D = 12 cm d = 9 cm		 D = 5.1 cm d = 4.5 cm	
Area A (cm^2)	63.6		49.5		4.4	
Inertia I (cm^4)	322.1		695.8		12.7	
Slenderness (λ)	111.1		66.7		147.2	
Weight (kg)	8.7		8.7		8.7	
Max. force applied (kN)	15.1		25.6		27.6	
Price/m Colombia/Germany	2	5	1	3	4	8

Adapted from Laude and Obermann (2003)

buckling compared with sections of the other materials. At the same time, this material provides an optimum economic and ecological cost.

The latest research characterizing guadua, which formed the basis of Chapter G12 in the new Design Regulation NSR-10, was conducted by Luna et al. (2011). The allowable stresses were determined by trials for compressive stress, tensile stress, shear stress, impact bending, and perpendicular compressive stress in manometers of cepas, basa, and sobrebasa (Fig. 8) of guadua from three different areas in Colombia.

In the above-mentioned publication, the design methodology is explained by the way to determine allowable stresses; which is based on structural mechanics in the ISO 22156 Bamboo Structural Design standard, as well as various areas of research conducted at the national and international level. It details the process from coding and marking each guadua culm of between 3 and 5 years old, going through the process of measuring and cutting them, data digitization, and testing of specimens. Following the results of this study, recommendations on the allowable forces for guadua are given for three cases with different loads (Table 4).

The values for the modulus of elasticity are shown in Table 5. The value used for the analysis of structural elements should be E0.5. In the event of there being

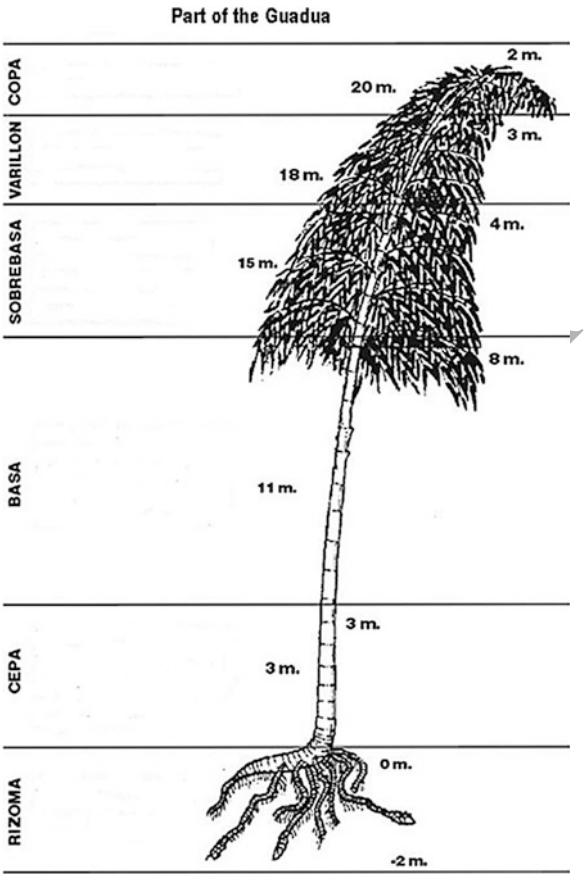

Fig. 8 Parts of the guadua (Stamm 2001)

Table 4 Allowable stresses for guadua (Units in MPa)

	Bending (Fb)	Tensile strength II (Ft)	Compressive strength II (Fc)	Tensile strength ⊥ (Fp)	Shear strength II (Fv)
A	8.3	9.0	4.5	0.4	0.8
B	10.4	11.3	5.6	0.5	1.0
C	12.5	13.6	6.8	0.6	1.2

Taken and adapted from Luna et al. (2011)
A Dead load, *B* Dead load + alive, *C* Dead load + live + wind or seismic), *Fb* Allowable bending stress, *Ft* Allowable tensile stress parallel to the grain, *Fc* Allowable compressive stress parallel to the grain, *Fp* Allowable compressive stress perpendicular to the grain, *Fv* Shear stress parallel to the grain

Table 5 Modulus of elasticity for guadua (Units in MPa)

Average modulus E0.5	Percentile modulus E0.05	Minimum modulus Emin
13,900	7800	3000

Taken and adapted from Luna et al. (2011)

critical service conditions or the requirement for a higher level of security, the deflections should be calculated using the E0.05. In any case, according to Luna et al. (2011), the choice of a suitable modulus of elasticity depends on the judgement of the structural engineer and must correspond to one of the values shown in Table 5.

3 Existing Regulations

Since January 26, 2010 an update of NSR-98 has been in force. It is called NRS-10, and in addition to one of the chapters being revised and lengthened, a new chapter has been added, in which guadua is considered a building material, (although it only applies in Colombia). The new chapter is entitled Chapter G12: Guadua Structures.

Chapter G12 is based on a series of studies undertaken by a civil-engineering group led by the engineer Caori Takeuchi at the National University of Colombia located in Bogotá. The studies were granted specifically for this update and supplemented by research and trials conducted by Luis Felipe López at the University of Los Andes. Tutoring was also provided by AIS (Colombian Association of Earthquake Engineering). The highlight of this chapter is the creation of reference values for the strength of guadua. Until now, guadua has been used in construction, but without standardized strength values. The experience gathered over time was used more than calculations, the latter substantiating the stability and strength of the structure through compliance with a regulation, which was previously nonexistent.

This is one of the first steps to get guadua recognized globally (in the short term) as a valid design material, as wood is.

Current existing regulations in Colombia, NTC (Colombian Technical Standard):

- NTC 5300. Harvest and postharvest of the *Guadua angustifolia* Kunth culm.
- NTC 530. Preservation and drying of the *Guadua angustifolia* Kunth culm.
- NTC 5405. Vegetative propagation of *Guadua angustifolia* Kunth.
- NTC 5407. Structural joints of *Guadua angustifolia* Kunth.
- NTC 5458. Making handicrafts and furniture from mature *Guadua angustifolia* Kunth culms.
- NTC 5525. Test methods to determine the physical and mechanical properties of *Guadua angustifolia* Kunth.
- NSR-10. Colombian earthquake resistant construction regulations.

Fig. 9 Exterior view of the ZERI Pavilion built in Manizales Colombia (Salas 2006)

Until an international standard is implemented (an initiative that the AIS is currently working on with the institutional support of the INBAR), for any design that includes *Guadua angustifolia* Kunth, it is advisable to follow the guidelines set out in the Colombian NTC and NSR10 standards.

As a representative example for the potential of guadua, the most renowned building designed in Europe with this material is shown in Fig. 9, classified as a large engineering structure for its importance and complexity.

The photograph in Fig. 9 shows the ZERI pavilion designed by the architect Simon Velez, which was first built in Manizales (a decagon of 2000 m^2 over two floors, 40 m in diameter with eaves overhanging 7.5 m) and subsequently built as a full-scale replica in Hannover (Germany). It is the best example of the use of guadua as a building material. The rigorous strength tests conducted by German professors in the replica were undertaken in the absence of bamboo engineering anywhere in the world and as such about $200,000 had to be invested in three studies: the first with Professor Klaus Steffens, Director of the Institute of Experimental Statistics at the University of Bremen; the second with the University of Stuttgart led by Professor Simon Otto Aicher Institut Graiff; and the third by the engineer Joseph Lindeman from Hannover, a specialist in the calculation of wooden structures.

These tests ultimately proved successful, as the pavilion withstood the same load tests as those applied to concrete constructions. This resulted in guadua being approved as a building material in one of the world's strictest countries regarding construction standards, thus recognizing guadua as a suitable building material worldwide.

4 Conclusions

The objective of this research falls within a range of topics that, in recent years, are generating growing scientific and technical interest in the international community and specifically in the field of materials and sustainable design. The aim is to devise a technical design, fully adapted to the current paradigms, which are increasingly demanding lighter, more energy-efficient, and environmentally friendly structures.

The present study demonstrates that *Guadua angustifolia*, is a strong, durable, flexible, eco-friendly, renewable, and sustainable natural material, making it structurally suitable for the efficient construction of "parral" type greenhouses. Since guadua provides great slenderness because of its tubular shape and optimum performance of the tested section, ideal to prevent buckling of its structure, it also constitutes a particularly suitable material for earthquake-resistant buildings.

This work, with a methodology and a structural design using a natural material, has the potential to generate a new trend in the greenhouse-construction industry in the Mediterranean area, especially in Almería, directly applicable to the development of new structures.

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Part VII
IT and Communications. Software Engineering

Evaluation of the State of Cutting Tools According to Its Texture Using LOSIB and LBP Variants

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Abstract The FRESVIDA project deals with the life assessment of cutting tools working under severe conditions using digital image processing techniques. The description of texture in materials through artificial vision techniques is very useful for this goal. There are several works based on Local Binary Patterns (LBP) and many variants such as Local Binary Pattern Variance (LBPV) or Diamond-LBP Code (DLBPCS) that have proved to be effective when distinguishing materials according to their texture. The Outex dataset comprises images from 24 materials acquired under different illumination conditions, becoming the present reference dataset for texture evaluation. In this work, several descriptors have been extracted based on the LBP from the Outex dataset, as well as their combination with LOSIB (Local Oriented Statistical Information Booster). All of them have been classified with Support Vector Machine (SVM) to assess which one is more useful for the above-mentioned task. In this case, all descriptors achieve a lower performance level combined with LOSIB because Outex is a data set that studies rotation invariances.

Keywords Texture · Computer vision · Cutting tools · Local binary pattern

1 Introduction

The development of control techniques for the detection of tool wear in machining processes is a key factor in automated production systems. Tool Condition Monitoring Systems (TCMS) drastically reduce manufacturing costs. On the one

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hand, TCMS decrease the amount of time used by an operator to make an inspection. On the other hand, they help to avoid breakdowns that are sometimes undetectable by a worker. In the last years, the search of techniques for automated tool wear estimation has become very relevant due to the birth of high-speed machinery, which causes a significant reduction of the life cycle of the cutting tools.

The University of León is participating in the FRESVIDA research project, funded by the Spanish Government, which aims at developing a system capable to determine the life cycle of milling cutting tools by means of a fusion of acoustic signals, vibrations and visual information of the worn areas. This project arises as an answer for the industrial necessity of TECOI, a company specialised on the production of tool machines. Figure 1 shows two examples of milling head tools that contain cutting tools, also called inserts. On the right, the head tool that is used in this project is shown.

Weckenmann and Nalbantic (2003) demonstrated that the cost of changing cutting tools can sum up to a twelve per cent of the total production cost. For this reason, there is a high economic interest on the improvement of the efficiency of the tool monitoring systems (Kopac 1998). Furthermore, it has been established that around a 20% of the non-productive time in modern manufacturing systems is due to cutting tools failures (Kurada and Bradley 1997).

For all these reasons, tool wear monitoring in real time has become an active research field that aims at eliminating the subjectivity of the operators while using objective criteria to predict the appropriate time to replace a cutting tool. Lim (1995) concluded that the use of sensors to estimate the ideal moment of cutting tool replacement would reduce up to a 40% the production costs. Based on this theory, several works have emerged in the last years such as the ones by Painuli et al. (2014), Wang et al. (2014) or Fernández-Abia et al. (2014).

Fig. 1 On the *left*, an example of a milling head tool. On the *right*, the milling head tool model employed in this project

In this context, the use of artificial vision and, more precisely, texture analysis becomes very interesting. It allows for the development of a precise and efficient system that determines the state of the tool in real time without the effect of usual problems like noise, which may affect the force sensors, vibrations, etc. Several researchers have studied artificial vision techniques to determine the state of cutting tools (Alegre et al. 2008). They are based on different approaches such as the Wavelet transform (Morala-Argüello et al. 2012), Laws descriptors (Alegre et al. 2012), contour signatures (Alegre et al. 2009) or descriptors based on moments (Barreiro et al. 2008).

Texture analysis is an intricate problem on the field of artificial vision, whose purpose is the description of the spatial variability of an image considering the intensity level of its pixels.

In the last years, several research fields have used approaches based on texture analysis to automate processes. For example, in the biological field, García-Olalla et al. (2015) proposed a system based on a combination of Local Binary Pattern (LBP) (Ojala et al. 1994) information extracted from the Wavelet transform and Fourier moments in order to determine the integrity of the acrosome of boar spermatozoa, yielding a hit rate higher than 99%. González-Castro et al. (2012) proposed a method that classifies texture by means of descriptors based on adaptive Mathematical Morphology without a priori knowledge about the texture.

The LBP is becoming one of the most popular techniques due to its simplicity and high discriminant power. Many research groups are working on creating algorithms based on LBP (García-Olalla et al. 2013). Guo and its research group have performed several modifications of LBP like Adaptive LBP (ALBP) (Guo et al. 2010a, b, c), Completed LBP (CLBP) (Guo et al. 2010a, b, c) or LBP Variance (LBPV) (Guo et al. 2010a, b, c). In the industrial environment, Tajeripour et al. (2007) proposed a modification of LBP to detect defects on manufacturing processes, achieving results with a hit rate higher than 95%.

One of the most widely used datasets in the study of the behaviour of texture descriptors is Outex. Outex was developed by Ojala et al. (2002a, b) and currently it is still a reference dataset for the evaluation of new descriptors. For this reason, many researchers have used these images to verify their works. Ojala et al. (2002a, b) used this dataset to verify the good use of uniform LBP. Other examples of works that use Outex are: Ahonen et al. (2009) or more recently Yuan (2014) or Zand et al. (2015).

The objective of this paper is to carry out a study of different texture description methods based on LBP using the Outex dataset. In this way, possible useful descriptors can be determined in the application field of the FRESVIDA project, which is focused on the tool wear estimation in milling machines.

The rest of the paper is organized as follows: in Sect. 2 the different types of evaluated descriptors are explained. The experiments, the dataset and the obtained results are shown in Sect. 3. Finally, conclusions are drawn in Sect. 4.

2 Methodology

2.1 Software Engineering

In order to carry out this project, a software engineering method based on iterative and incremental development known as "Agile development" has been chosen. This scheme eases the development of the project by means of collaboration between self-organizing groups and communication between team members and clients. This development method is based on delivering periodically a usable software solution to the customer. For each delivery, the customer carries out an analysis of the delivered prototype and makes a list of priorities that must be accomplished in the next deliverable. In this case, a 1-week period between each delivery was used because of the fluent communication existing among the artificial vision and machining groups.

This type of development simplifies the programmers' work because the objectives to be accomplished are very specific. Moreover, due to the good and periodic communication between the programmers and the machining experts group, mistakes due to the lack of knowledge of the software development group could be solved easily without causing a bad implementation that leads to a non-optimal solution or to delays in the project schedule.

2.2 LBP

The Local Binary Pattern (LBP) (Ojala et al. 1994) is a simple but effective texture operator that labels each pixel of an image with a binary value using a threshold based on its neighborhood.

Due to its low computational cost and high discriminative power, LBP has become one of the most used methods in applications related with texture analysis. The most important advantage of LBP in real applications is its robustness against changes in the gray level intensity, caused by differences in illumination, among other things.

The LBP is calculated on grayscale images by means of Eq. (1), where P is the number of pixels taken into account in the neighborhood, R is the neighborhood size and g_c and g_p are the gray level values of the central pixel and each of the p pixels of the neighborhood respectively.

$$LBP_{P,R} = \sum_{P=0}^{P-1} s(g_p - g_c)2^p, \quad s(x) = \begin{cases} 1 & if \quad x \geq 0 \\ 0 & if \quad x < 0 \end{cases} \tag{1}$$

In Fig. 2, the process is shown graphically.

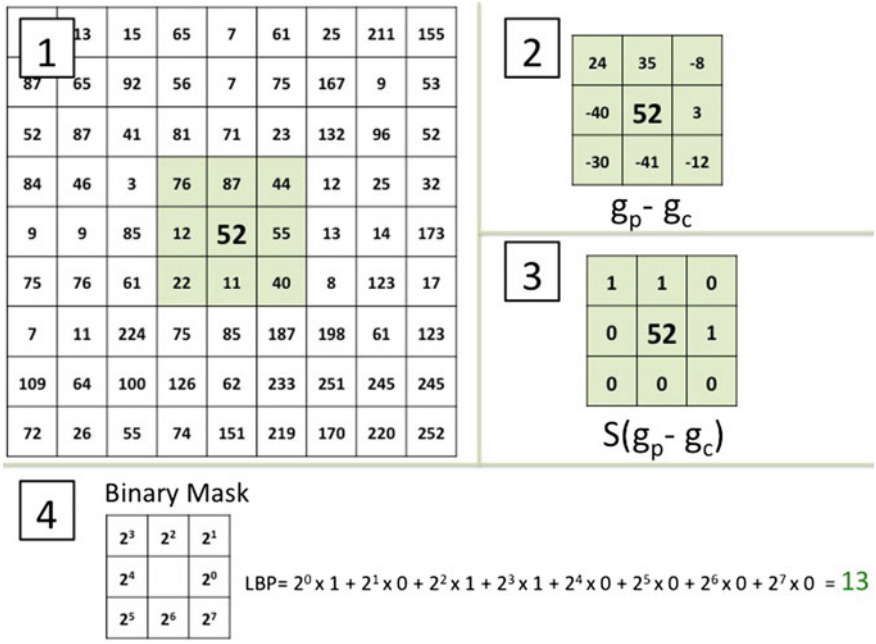

Fig. 2 Visual example of the extraction process of the corresponding value to LBP for a specific pixel

2.3 ALBP

Guo (2010a) proposed a new texture descriptor based on LBP, which is focused in obtaining information not extracted in the original method. In this case, the method was focused in adding information of the texture orientation. The method minimizes the average variations and the standard deviation of the directional differences. Therefore, it was proposed to add an extra parameter w in the Equation $|g_c - w_p * g_p|$. The objective function is defined in Eq. (2).

$$w_p = \arg_w \min \left\{ \sum_{i=1}^{N} \sum_{j=1}^{M} |g_c(i,j) - w \cdot g_p(i,j)|^2 \right\} \tag{2}$$

where w_p is the element used to minimize the difference of the direction p and N and M are the number of rows and columns of the image respectively. Therefore, the final equation of the Adaptive Local Binary Pattern (ALBP) is defined as it is shown in Eq. (3).

$$\mathrm{LBP}_{\mathrm{P,R}} = \sum_{\mathrm{p}=0}^{\mathrm{P}-1} \mathrm{s}\left(\mathrm{g}_{\mathrm{p}} - \mathrm{w}_{\mathrm{p}} \cdot \mathrm{g}_{\mathrm{c}}\right) 2^{\mathrm{p}}, \quad \mathrm{s}(\mathrm{x}) = \begin{cases} 1 & \text{if} \quad x \geq 0 \\ 0 & \text{if} \quad x < 0 \end{cases} \tag{3}$$

2.4 CLBP

The same research group that developed LBPV and ALBP presented another method called CLBP (Completed LBP), which tries to generalize and complete the information that the original method provides (Guo et al. 2010a, b, c). In this method, a local region of the image is represented by its central pixel and a Local Difference Sign-Magnitude Transformation (LDSMT). The LDSMT splits the local structure of the image into two complementary components: the sign difference that matches with the classic LBP, called CLBP_S and the magnitude difference CLBP_M, which is defined using Eq. (4).

$$\mathrm{CLBP\_M}_{\mathrm{P,R}} = \sum_{\mathrm{p}=0}^{\mathrm{P}-1} \mathrm{t}\left(\mathrm{g}_{\mathrm{p}} - \mathrm{g}_{\mathrm{c}}, \mathrm{c}\right) 2^{\mathrm{p}}, \quad \mathrm{t}(\mathrm{x}, \mathrm{c}) = \begin{cases} 1 & \text{si} \quad \mathrm{x} \geq \mathrm{c} \\ 0 & \text{si} \quad \mathrm{x} < c \end{cases} \tag{4}$$

where c is a threshold defined adaptively. Usually, the average value of all the magnitude differences in the image is used.

2.5 LBPV

Guo and his colleagues proposed Local Binary Pattern Variance (LBPV) as a combination of LBP and a contrast distribution method (Guo et al. 2010a, b, c). LBPV uses the image variance as an adaptive weight to adjust the contribution of each value of the LBP in the histogram calculation. LBPV is calculated according to Eq. (5).

$$\mathrm{LBP}_{\mathrm{P,R}} = \sum_{\mathrm{i}=1}^{\mathrm{N}} \sum_{\mathrm{j}=1}^{\mathrm{M}} \mathrm{w}\left(\mathrm{LBP}_{\mathrm{P,R}}(\mathrm{i}, \mathrm{j}), \mathrm{k}\right), \mathrm{k} \in [0, \mathrm{K}], \tag{5}$$

where k represents the histogram values, K is the maximum value of the LBP and w is defined in Eq. (6).

$$\mathrm{w}(\mathrm{LBP}_{\mathrm{P,R}}(\mathrm{i}, \mathrm{j}), \mathrm{k}) = \begin{cases} \mathrm{VAR}_{\mathrm{P,R}}(\mathrm{i}, \mathrm{j}), & \mathrm{LBP}_{\mathrm{P,R}}(\mathrm{i}, \mathrm{j}) = \mathrm{k} \\ 0 & \text{in other case} \end{cases} \tag{6}$$

The neighborhood variance $VAR_{R,P}$ is defined in Eq. (7).

$$VAR_{P,R} = \frac{1}{P}\sum_{p=0}^{P-1}(g_p - \mu)^2, \tag{7}$$

where μ is the mean of the neighborhood.

2.6 LOSIB

The main goal of the Local Oriented Statistical Information Booster (LOSIB) proposed by García-Olalla et al. (2014), is to enhance the performance of texture descriptors. The main idea of LOSIB is to add local oriented statistical information computed along all pixels of the image.

This information is rarely taken into account when describing textures even though it provides very useful data about them. In this work, LOSIB is combined with other texture descriptors by concatenating it with the corresponding feature vectors.

The first step to obtain LOSIB is to extract the absolute differences d_p between the gray-level values g_c and g_p for all pixels c of the image, as shown in Eq. (8).

$$d_{p(x_c,y_c)} = |g_c - g_p| \tag{8}$$

Given a pixel c, the coordinates (x_p,y_p) of its neighbor p are extracted following Eq. (9).

$$\left(x_p, y_p\right) = \left(x_c + R\cos\left(\frac{2\pi p}{P}\right), \quad y_c - R\sin\left(\frac{2\pi p}{p}\right)\right) \tag{9}$$

The values of neighbors that are not in the grid center can be estimated by interpolating their connected pixels. Then, the mean of all differences along the same orientation is computed by means of Eq. (10), where N and M are the number of rows and columns of the image, respectively.

$$\mu_p = \frac{\sum_{x_c=1}^{M}\sum_{y_c=1}^{N} d_p(x_c, y_c)}{M \times N} \tag{10}$$

So in the end, LOSIB comprises as many features as neighbors in the neighborhood and gives information about the mean of the gray level difference for all the orientations along the image.

3 Experiments and Results

3.1 Outex

The Outex dataset has been used to evaluate the different description methods due to its high popularity in experiments involving texture description for the last years. Two different tests proposed by the Outex developers have been carried out: Outex_TC_00010 (TC10) and Outex_TC_00012 (TC12), both of them composed by 24 different textures. Each texture has been taken under three illumination conditions ("Horizon", "inca" and "tl84") and nine rotation angles (0°, 5°, 10°, 15°, 30°, 45°, 60°, 75° and 90°). Furthermore, 20 different patches without overlap of 128 × 128 pixels have been created for each texture, illumination and angle.

In this work, the same experimental setup used in the state of the art related to Outex has been chosen:

1. In the TC10 experiment, the classifier is trained with the illumination "inca" and an angle of 0° for each texture and the other eight angles in each texture for the same illumination are used for testing in the classification. Hence, the size of the training set is 480 (24 × 20) and the number of test set is 3480 images (24 × 8 × 20).
2. In the TC12 experiment, the classifier is training with the same training set of the first experiment composed by 480 images and the test set is composed of all the other two illumination images ("horizon" and "tl84"). In that case, the number of images in the test is 4320 (24 × 20 × 9) for each illumination.

In Fig. 3, a brief subset of the images is shown, which yield Outex and their different illumination conditions.

3.2 Results

The SVM (Support Vector Machine) was used as classifier, due to the high performance that it has achieved in this kind of experiments, for both tests: TC10 ("inca") and TC12 ("horizon" and "tl84"). Figure 4 depicts the achieved results. In contrast with what was expected, the tests carried out using only the LBP-based descriptors outperform in all the cases the corresponding descriptors concatenated with LOSIB. These results can be explained taken into account the high requirement of Outex against rotational invariance, which is not considered by LOSIB. In the work carried out by García-Olalla et al. (2014), the evaluated dataset (KTH TIPS2-a) was not focused in the rotation but in the illumination and scale, where LOSIB performance is higher.

Considering only the methods based in LBP, the best result was obtained using LBPV with 16 neighbors, which makes it a clear candidate to be used in the

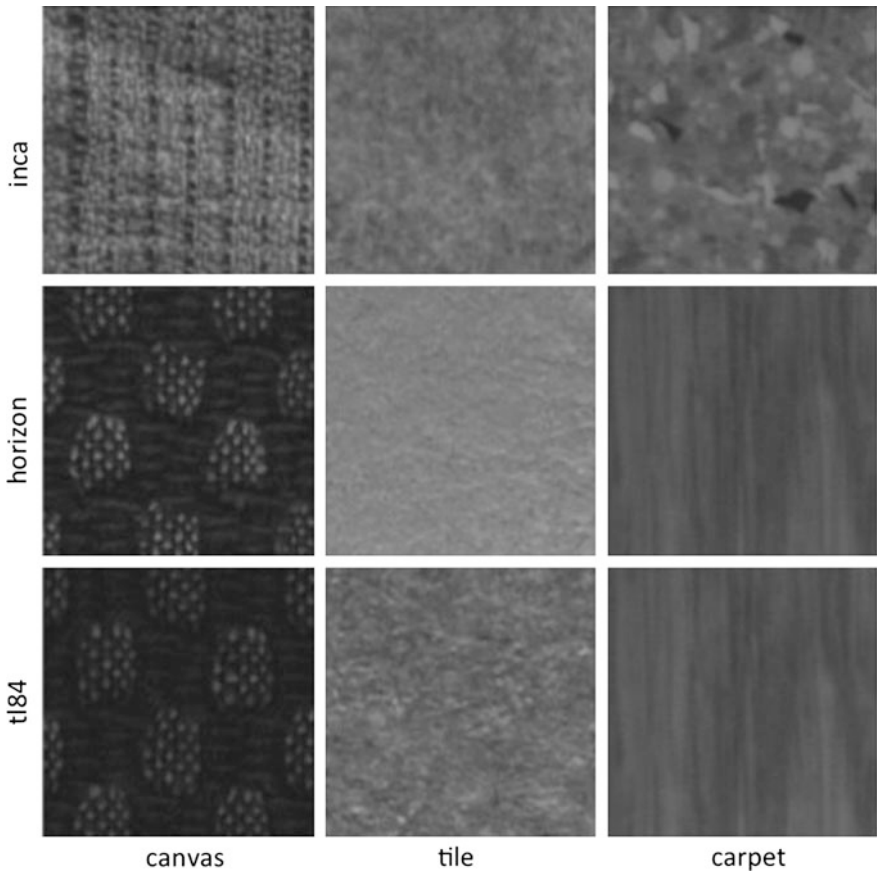

Fig. 3 Example of the Outex images. Each row corresponds to a different illumination type and each column to an example of the different textures

FRESVIDA project in order to detect the wear of inserts in milling processes. Regarding the results, it is remarkable the higher performance achieved by using a neighborhood of 16 instead of the smallest one of just 8.

In Table 1, the numeric results for each evaluated test using LBP variants are presented. The results of the LOSIB concatenations are not shown, due to the poor performance that they achieved (see Fig. 4).

The difference in the results for the three illuminations results is very significant: more than the 20% of hit rate in some cases. The LBPV has become the best descriptor for all the experiments, being the neighborhoods 8 and 16 the best solutions for TC10 and TC12 respectively.

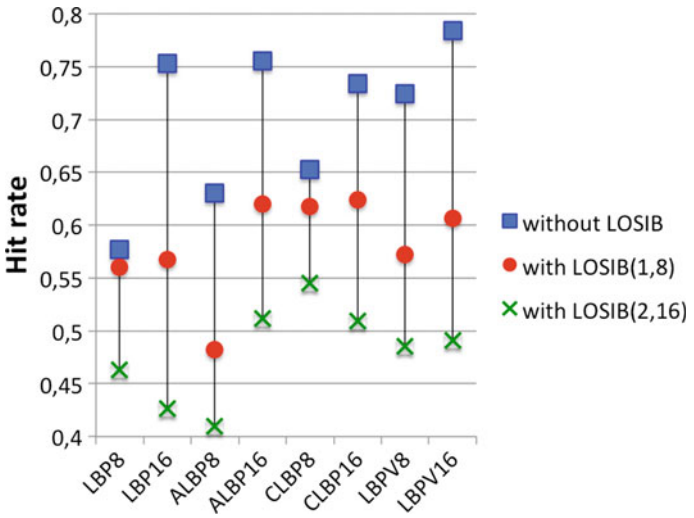

Fig. 4 Mean Hit rate for the three illuminations using LBP-based descriptors alone and also combined with LOSIB

Table 1 Hit rate for all the experiments evaluated using different methods based on LBP and the mean value of them

	TC10	TC12		Mean
	"inca"	"horizon"	"tl84"	
LBP8	0.6071	0.5590	0.5653	0.5771
LBP16	0.8313	0.6917	0.7366	0.7532
ALBP8	0.7518	0.5606	0.5780	0.6301
ALBP16	0.8247	0.7044	0.7377	0.7556
CLBP8	0.8115	0.5630	0.5843	0.6530
CLBP16	0.8440	0.6572	0.7013	0.7342
LBPV8	0.8607	0.6387	0.6727	0.7240
LBPV16	0.8495	0.7192	0.7833	**0.7840**

The best result is written in *bold*

4 Conclusions

In this paper an assessment is carried out, of different texture description techniques in a system for milling machines tool wear monitoring. Specifically, these methods are evaluated using the image dataset Outex—a state-of-the-art dataset in texture classification. The results of the experiments have shown that the methods based on Local Binary Patterns work quite well describing textures even if they have been rotated or subjected to changes in illumination. Classifications, carried out using SVM, indicate that the best method has been LBPV, which achieved a mean hit rate of 78.40% over the three experiments with different illuminations. It is remarkable

that the best hit rate achieved using this descriptor was 86.07%, obtained with the "inca" illumination. Such results allow us to consider using this technique in an automatic tool wear monitoring system based on image processing, under the framework of the FRESVIDA project.

Another test carried out in this paper consisted in combining the aforementioned descriptors with LOSIB, a texture descriptor presented in 2014 that has proved to be very successful in combination with LBP. However, the results in this case have been much lower than the ones obtained using both methods separately, mainly because the Outex dataset was designed mainly to assess rotation invariant methods, as the images of each class are rotated.

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Part VIII
Safety, Labour Risks and Ergonomics

SAFEBUS: A New Active Safety System for Pedestrian Detection in Public Passenger Buses

Juan F. Dols Ruiz, Leopoldo Armesto, Vicent Girbés and Laura Arnal

Abstract Although passenger vehicles have lower accident rates in urban areas than in suburban ones, there are low-speed maneuvers with higher risk of collisions with pedestrians and more serious injuries accidents. This fact makes necessary the use of Advanced Driver Assistance Systems (ADAS) for pedestrian detection in the vicinity of the vehicle. This paper describes part of the results obtained in the development of the project "Integral Advanced Safety Systems for Buses" (SAFEBUS). Specifically, it focuses on the development of a new active safety system to be used in situations of low-speed operation, where the vehicle is approaching or leaving bus stops. The results obtained are based on the development of a system for pedestrian detection in the front and right side of the vehicle (doors), a warning device for alerting the driver, which uses haptic and audiovisual feedback systems (pedals and steering wheel column), and signals generated for acting on the emergency braking system of the vehicle. Likewise, the experimental validations performed for the implementation of the system are described, which have shown the capability to alert the driver and, if necessary, stop the vehicle in dangerous situations to avoid pedestrian accidents.

Keywords Active safety system · Public transport buses · Pedestrian detection

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1 Introduction

Currently, passenger transportation is an economic sector of increasing strategic importance as it contributes to improve the competitiveness and development of other sectors in industrialized countries, such as industry, trade and tourism. Buses and coaches are key elements of public passenger transportation systems, and contribute socio-economically to the promotion of tourism, to energy saving, environmental protection, road safety, mobility and the economy. No other mean of collective passenger transport plays such an important role in all these areas at once.

Given the need to increase safety in urban mobility, where the traffic is getting more and more congested, the World Health Organization, in its report on the global status of road safety and its support for the initiative of the decade of action (2011–2020), has established in its conclusions the need for governments to ensure that public transport systems were safe, accessible and affordable (WHO 2013). In this sense, given that buses and coaches account for 55% of public transport in Europe, constituting the other land transport modes—rail, tram and metro—the remaining 45%, the search for solutions to improve active and passive vehicle safety has become a top priority of all passenger transport operators (ASCABUS 2013).

Currently, road transportation of passengers in bus and coach is the safest in Europe, with the same safety level as railways, despite sharing infrastructure with other users and means of transport. Thus, between 2007 and 2008, bus and coach passengers accounted only for 0.57% of deaths in the European Union (CARE 2009). In Spain, in 2012 there were 1726 accidents in which a bus was involved (counting fatalities, serious and slight injuries), being 83% of them in urban roads and the remaining 17% in interurban routes. Still, in 2012, only in 2% of the total percentage of accidents were buses and coaches involved, compared with 57% where cars were involved, 20% where motorcycles were involved or 5% with vans involved (DGT 2013).

It is also known that many of the incidents involving bus accidents occur in situations where there are no impacts between vehicles. Kirk et al. (2001) concluded in a study conducted in Great Britain between 1994 and 1998 that 63% of deaths or serious injuries occurred in no-impact accidents, a 94% of these accidents taking place in urban areas (with speed limited up to 30 mph). Similarly, Berntman et al. (2010) evaluated the safety of buses from data provided by the police and hospital injury reports, including in the study journeys to/from the bus stop, as well as boarding and getting off the bus, concluding that most injuries aboard occur as a result of an abrupt change in vehicle speed (60% when braking and 25% when accelerating), mainly affecting elderly and disabled people.

The latter is the most vulnerable group, accounting for over 50% of accident victims, both as passengers (more harmfulness leaving the vehicle than accessing it) and as pedestrians (when accessing the bus stop). Indeed, one of the most difficult problems to solve in order to reduce the accident rate of public transport vehicles is

one that occurs with low stature users, who are outside the driver field of view and try to cross the road in front of or behind the vehicle, just when it restarts the movement. This problem is even bigger in case of children or people in wheelchairs.

In this sense, one of the few standards regulating this safety issue can be found in the German regulation StVZO 34th, that establishes that all buses used to transport children are to be designed in a way that the driver is able see from his seat a child of less than 1.2 m of height at a distance of 1 m from the front, also extending to the side from the vehicle front pillar (Garcia et al. 2003). The use of mirrors is, in the vast majority of cases, inadequate, since a child can quickly change position and the driver does not detect it immediately because he is not looking at that moment or simply because the child is so small that he fails to see him. Therefore, the use of safety systems at the periphery of the bus is increasingly indispensable at low-speed maneuvers, where pedestrians move around the vehicle.

Consequently, despite that bus accident figures are significantly lower than those of other transport means and similar to those of railways, the continuous improvement of safety in buses is the main field of technological development within the sector. For this reason, the Integral Advanced Safety Systems for Buses project (SAFEBUS) (IPT-2011-1165-370000), funded by the Spanish Ministry of Science and Innovation, was developed between May 2011 and January 2014. The project was executed by a consortium of technology companies and universities coordinated by Cognitive Robots, S.L., and participated by the Polytechnic University of Valencia, Centro Zaragoza, Castrosua S.A. and the Biomechanics Institute of Valencia.

This project aimed to develop advanced safety systems (active and passive) in buses, which allowed a reduction in the frequency and severity of accidents during urban transport (accidents and falls associated with standing passenger injuries, wounds sustained when accessing and exiting a bus, etc.), through technologically advanced and ergonomic solutions that could be integrated in buses and coaches for public passenger transport.

Other specific objectives were the need to identify the types of events occurred in the entry and exit movements of passengers and their impact, the development of a comprehensive system for pedestrian and obstacle detection for driving assistance at low speeds, the improvement of vehicle safety surrounding bus stops, the development of new passive safety systems for the passenger compartment ergonomically adapted to the user, and the establishment of new test protocols and simulation to evaluate the effectiveness of new designs and safety systems developed under normal operating driving conditions.

This paper presents some partial results of the project SAFEBUS. Specifically, the content will be focused on the description of the ADAS active security systems, audio-visual and haptic feedback systems developed for driver assistance, that allow the bus driver to detect pedestrians during low speed maneuvers in urban environments.

2 Active Safety Systems to Detect Pedestrians in Urban Bus Public Transportation

During the last decade, many sensors that warn the bus driver about pedestrian or objects that are too close to the vehicle body have been developed. Usually, these systems are called ODS (Object Detection System), giving to the driver visual and acoustical warning signals once an object in the area surrounding the vehicle is detected (up to 3 m) (Dunn et al. 2007). ODS systems are typically based on LIDAR, RADAR, Ultrasound, or Computer Vision technologies, etc.

According to Garcia et al. (2013), the active safety systems that have greater effectiveness in urban environments are those based on warning systems for front or side collision, pedestrian accidents or emergency braking. This set of assistive devices are included in what is known as Advanced Driver Assistance Systems (ADAS), which allow intervention on the state of driver attention by using visual, haptic or auditory devices. From all the possible ADAS to be used in urban settings, those acting at low speed to detect the presence of pedestrians in the vicinity of the vehicle are of special relevance. This is the case of urban buses, that modify the driver's behavior by sending stimuli to improve the decision making process and traffic safety, thus preventing pedestrian accidents, helping the driver to take evasive maneuvers or emergency braking (Gandhi and Trivedi 2006; Geronimo et al. 2010). Therefore, monitoring the vehicle environment also plays an important role in ADAS systems, demanding a large number of sensory fusion, such as laser scanning (Garcia et al. 2011), and video to detect pedestrians (Kaempchen and Dietmayer 2004; Schneider and Gavrila 2013). There have also been efforts to develop driver feedback elements, where haptic interfaces, such as pedals to control the deceleration, are gaining more and more importance (Mulder et al. 2009).

In the ADAS, the driver has an important role in defining the design requirements. This has led towards research to the interaction of people with these systems, as in the case of driving based on user selectable maneuvers (Kauer et al. 2010). Other studies have been focused on the design of interfaces dedicated to meet the needs of drivers, development of components for man-machine interaction, both visual and haptic, within the concepts of speed and safe distance (Adell et al. 2008a), combining driving preferences of users and safety margins to generate optimal maneuvers (Biral et al. 2005). At present, there are already systems with speed adaption and haptic feedback on the pedal. Some studies show the benefits of including these systems in the control chain of a vehicle (Nilsson 2002; Adell et al. 2008a, b, 2011), while other researches try to analyze the driver's adaptation to the new device, showing that after a certain time he is capable of improving his driving decision making (Varhelyi et al. 2004; Hjalmdahl and Varhelyi 2004).

3 SAFEBUS Active Safety System

The active safety system developed in the SAFEBUS project aims at the detection of persons in the vicinity of an urban bus, using vision systems and focusing on the problem of detection in events with speed below 15 km/h during bus stops manoeuvers. The system detects people from an overhead view, while a head-on frontal camera detects people at a greater distance. The project has developed a set of devices that alert the driver via audio-visual feedback with a panel display installed on the bus dashboard and haptic devices in order to make the driver aware of the danger. It should be noted that in no case the developed devices ensure the absence of collisions, since the solution adopted to act preventively, allows the driver to control the bus at all times. In any case, if the bus runs at very low speed (<5 km/h), to ensure the absence of collisions if the above preventive measures are insufficient, an emergency signal could be activated to immobilize the engine.

Figure 1 shows the selected positions for the location of various sensors and haptic devices, which were used for the validation of the project results. These sensors covered the right side (1); front (top) closer to the periphery of the bus (2); front covering a distance from 2 m (3). Since the system is modular, cameras can be placed in other blind spots, such as the back of the bus or the left side. However, these areas were not covered because the experimentation only focused on avoiding

Fig. 1 Conceptual diagram of the active safety system developed in SAFEBUS project

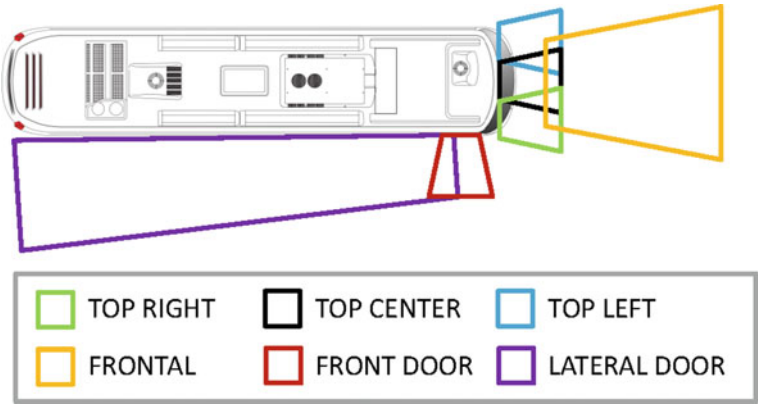


Fig. 2 Detection zones of the SAFEBUS project active safety system

collisions on the front and right side, although in the previous developments were referred (Armesto et al. 2015).

A top view of the zones covered by the cameras is depicted in Fig. 2. Moreover, the proposed solution includes a set of audio-visual and haptic warning devices for the driver, also shown in Fig. 1. Specifically, these systems are: monitoring system or audio-visual feedback (4), in which the set of images captured by the cameras with the Regions Of Interest (ROI) for each detected person can be seen, generating sound according to the detected situation; an accelerator pedal with haptic feedback (5), consisting of a pedal lever to eject the accelerator, alerting the driver so that the moving off operation is potentially dangerous; a retention system (torque) of the steering column (6), without full blocking but strong enough to make drivers aware that a particular direction of motion is not recommended.

Figure 3 depicts a diagram with the relationships of the different processors installed in the bus, here referred as nodes. The nodes are implemented on the embedded card "ODROID-U2", which uses a quad-core ARM processor Samsung Exynos 4412 Prime (Cortex-A9) at 1.7 GHz. Besides, they include a Linaro 12.11 distribution (kernel 3.8.13.14-RT30 armv7l) based on Ubuntu as OS. ROS Groovy (Quigley et al. 2009), an agent-based software architecture, has been adopted for communication between different nodes. The "Master" node of Fig. 3 is responsible for different functions of the developed application: (1) monitoring CAN communication of DICO subsystem (Drive Control Unit) of the bus, which publishes via CAN bus the speeds of wheels and shaft, and the run mode DNR (Direct-Neutral-Reverse), among other information; (2) serial communication management with a DSP that controls haptic throttle and the emergency braking signal; (3) construction of an occupancy map of the obstacles (people) detected from the information received by the "Smart Cameras" nodes; (4) Web server of the images captured by the cameras properly combined. The screen where the images are displayed is actually a touch Panel-PC, with the only requirement of being able to run a web browser to display the images and have a stereo audio output to the

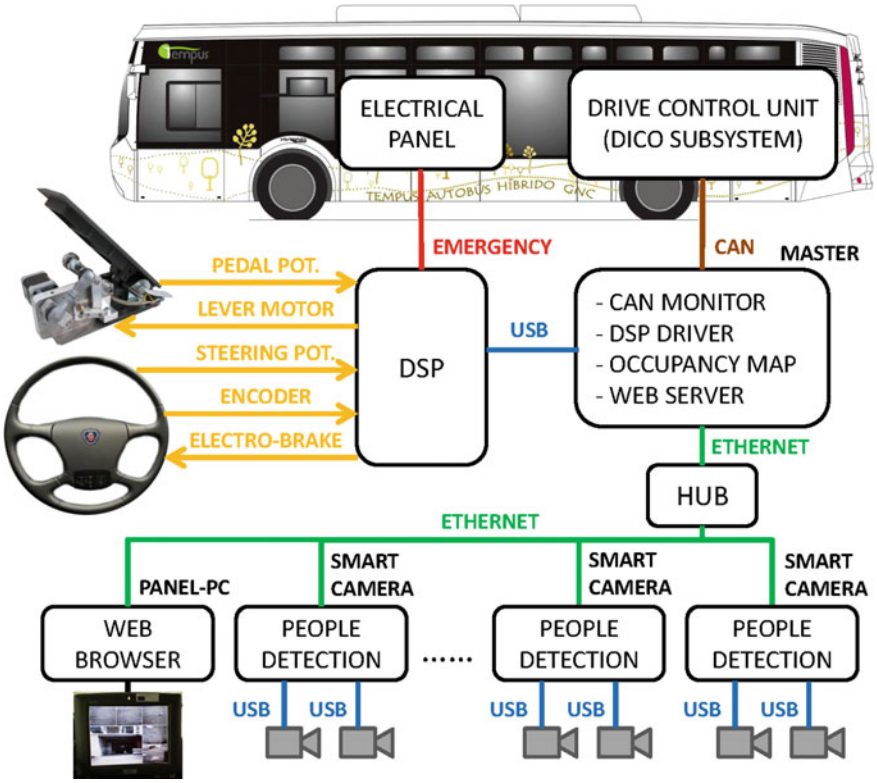


Fig. 3 Relationship between nodes, devices and vehicle detection system of people, haptic and audio-visual feedback

beeper. The "Smart Cameras" nodes are able to capture images from digital USB cameras, process them and send the results of processing tasks to the "Master" node.

3.1 Pedestrian Detection System

The pedestrian detection system uses a network of smart stereo cameras that allow image acquisition to detect people by their appearance and 3D data to detect them by their volume. The system includes the following processing stages:

Acquisition. Pairs of images from stereo cameras are acquired at 15 FPS (frames per second). Then, a homogeneous transformation is applied to make them coplanar. This allows objects to appear in the same row in both images, speeding up the disparity calculation.

Disparity. It computes the disparity between left and right images based on the Sum of Absolute Differences (SAD) technique (Richardson 2004).
3D projection. It gets a 3D point cloud based on the epipolar geometry of the stereo system (Hartley and Zisserman 2004). Moreover, it generates a list of points corresponding to all objects in the scene.
Segmentation. Cylindrical objects from the 3D point cloud are extracted robustly based on Random Sample Consensus (RANSAC) technique (Fischler and Bolles 1981). In this regard, people are approximated to cylindrical objects. Furthermore, different filters are applied to cylinders such as vertical geometric relationships and radius size.
HOG classification. It detects people by appearance based on the technique of HOG (Histogram of Oriented Gradients). The system uses a cascade classifier (type boost) to discriminate people in the image (Zhu et al. 2006), generating ROIs (in the plane of the image) to the position and size of individuals.
Optical flow. It gets the video (consecutive sequence of images) to estimate the speed of ROIs (Lucas and Kanade 1981). To calculate the average displacement of pixels in a region, the RANSAC technique is used to filter out spurious data (pixels moving in a different direction with respect to the majority of pixels).
Tracking. It allows data fusion between ROIs position returned by the HOG classifier and the velocities of these regions estimated using Kalman based optical flow (Kalman 1960). The states vector of the Kalman filter contains the position and velocity of the center of the region. The position of the region obtained from HOG and its velocity through optical flow are the filter measurements. Regions correspondence maximizes the common area (Enzweiler and Gavrila 2009).

3.1.1 Training

People detection with HOG requires a classifier properly trained for the specific purpose of the application. In this case, four cameras (three upper and one in the front door (see Fig. 2) are oriented with a strong inclination, pointing to the ground. From this position the appearance of a person is significantly different to that used by the vast majority of repositories (Dollar et al. 2009, 2012). Therefore, in the context of the project a set of recordings were made in different places in the city of Valencia and surroundings, with the purpose of acquiring sample images representing a person from the perspective of the above cameras, so as to train the classifier based on HOG. Specifically, around a bus different types of people can be found, particularly with suitcases, bags and of different ages, disabled people and children. In this sense, places in which there was a large movement of people—with significant variation in appearance, ages and positions—were sought. Thus, images were taken in both the Polytechnic University of Valencia and the North Railway Station RENFE Valencia, where a large number of pedestrians with and without luggage and of different ages were found; the Polytechnic University Hospital "La Fe" with a wide range of people of different ages and mobility restrictions like

people with crutches or wheelchairs; and the Mas Camarena College (Bétera), to acquire images of children from 3 to 11 years.

In the case of whole body people, the detection rates were fairly high as it was possible to detect people in 97.3% of cases. Detecting partial people is very complex because variability in the appearance is notably higher, still, the system could successfully detect the 78.28% of the cases. Furthermore, it was observed that in 9.6% of the cases the system detects incorrectly, confusing any object with a person (false positive), typically shadows, stains, curbs etc. However, from all the images, only 5% of the cases could have been considered as false positives.

3.2 SAFEBUS Driving Assistive System

The driving assistance system consists of a risk collision assessment system; a haptic pedal powered by a locking lever; a steering column locked by an electromagnet-brake pad braking mechanism; a screen for displaying images captured by the cameras at different monitoring areas; and an acoustic warning stereo system.

3.2.1 Risk of Collision Assessment System

This system uses the position information from objects (or people) detected by the cameras. Figure 4 shows the location of the emergency zone that occupies an area of 4×3 m^2 in front of the bus, including part of the front door area. If an object is detected in the emergency area and the driver intends to start pressing the accelerator pedal, an emergency stop is generated from the activation of an electrical signal, as long as the speed is less than 5 km/h.

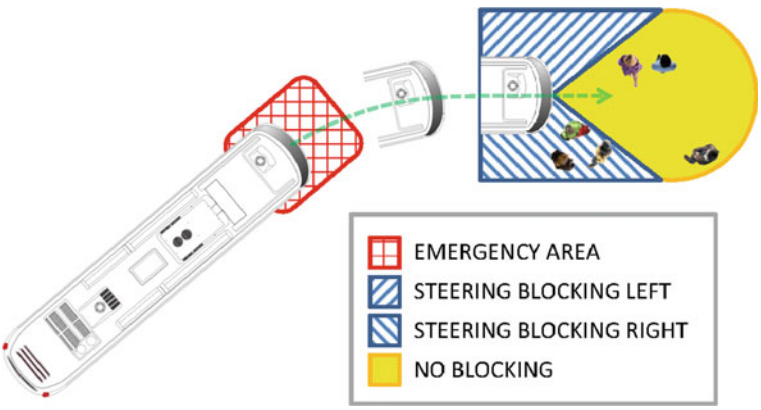


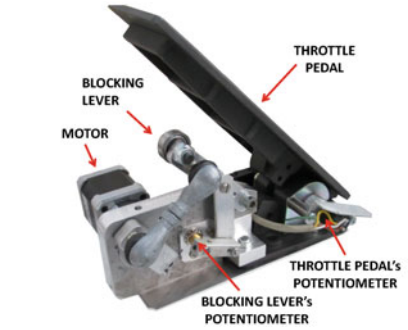
Fig. 4 Risk collision assessment

Otherwise, a risk of collision coefficient is calculated depending on the distance of the nearest object that potentially collides with the bus. From the driver's intention, estimated from the position of the gas pedal and steering wheel, the virtual path the bus would describe is calculated (Armesto et al. 2015). Figure 4 shows in dark blue the warning zone used to evaluate potential collisions along that path. The blocking of the accelerator pedal is proportional to the collision distance detected, while the blocking of the steering wheel is a function of the colliding bus side. If the object is in the yellow area of Fig. 4, the steering lock is deactivated, but this does not affect the calculation of the blocking of the acceleration pedal.

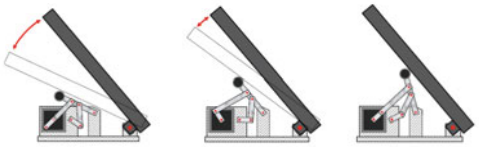
3.2.2 Haptic Feedback System

Figure 5a shows the accelerator pedal from a TEMPUS bus used in the project experiments, which incorporates a haptic feedback system consisting of a motorized four-bar mechanism with a lever to block and eject the throttle pedal in warning situations. It also incorporates two potentiometers, the first to close the control loop position of the blocking lever and the second one to measure the position of the throttle pedal.

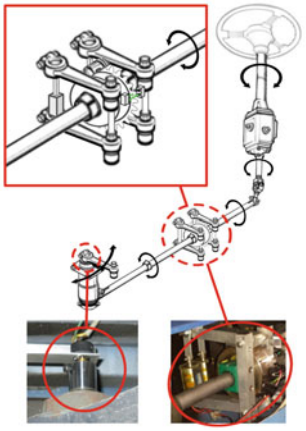
The system further includes a haptic feedback system to block the steering column. As shown in Fig. 5e, such mechanism consists of a brake pad that contacts a brake disc through the action of an electromagnet (the system includes a spring that retracts the brake pad in case of deactivation).



(a) Haptic Pedal from TEMPUS bus



(b) Non-blocking postion **(c)** Intermediate position **(d)** Blocking Position



(e) Steering column with active blocking system

Fig. 5 Haptic feedback systems

The system also includes two infrared sensors which beams are cut by a gear-wheel for determining the direction of rotation of the steering wheel, so that the driver perceives a constant rotational resistance in the case of turning the steering wheel in the locked direction. This force disappears when the driver turns the steering wheel towards the non-blocking direction. To know the driver's intention, the ADAS system includes an angular sensor in the steering column.

3.2.3 Audio-Visual Feedback System

An 8″-size screen for viewing the camera images has been installed, as shown in Fig. 6. This display is an AFL-08A Panel PC with an Intel Atom N270 1.6 GHz Fanless. As operating system, it incorporates a Linux Ubuntu 12.04 distribution. For the operation of audiovisual feedback on the screen, it only requires a web browser with ability to interpret HTML5 and *javascript*. A small web server, designed entirely in *javascript* is running in the "Master" node serving the flow of video cameras in MJPEG format, in addition to dynamically manage the activation of acoustic beeps and visual overlays to indicate states of emergency or warning.

The screen interface shows the upper right, center and left cameras in the top; in the lower left corner, with a size four times larger, the front camera is shown; while on the right side there are two more images corresponding to the two door cameras, included to improve driver visibility in the lateral part of the bus. The interface also recognizes tactile pulses onto the screen, allowing the driver to choose which camera is displayed in the central part, helping in certain maneuvers. When the emergency mode is activated, the risk element is correspondingly indicated in the center of each image. The auditory feedback consists of a beep on the speakers (stereo), which are integrated in the panel PC. The volume is adjusted in relation to the risk factor (Armesto et al. 2015), which plays equally on both speakers if the

Fig. 6 Audio-visual interface feedback System

person is detected in the center. On the other hand, the system only plays on the left or right speaker if the potential collision is detected in the corresponding direction.

4 Experimental Validation of the SAFEBUS Active Safety System

In order to validate the active safety system described, two types of experiments were conducted at the premises of Castrosúa SA Company, partner of the consortium, which lent a TEMPUS bus for performing the validation tests. These trials characterized the system operation in the presence of objects and people to detect false positives, which were filtered. Furthermore, the system was also validated in the presence of a ducked person, representing the case of a short stature pedestrian detection as would be a child.

In a first experiment, the person was located about three meters in front of the bus. The top-center and frontal cameras detected the person simultaneously. Data extracted from the experiment showed how the driver, after accelerating gently for about one second, could acquire a speed progressively on the bus to the person. During that point in time, the pedal locking mechanism was activated and retracted just after the driver stops accelerating. The acoustic beeps were equally generated in the panel PC. Because of the inertia, the bus continued approaching to the person even after driver had stopped accelerating. When the bus approached the person at a distance of 1.5 m, an emergency braking was activated immediately in order to stop the bus.

In a second experiment, the aim was to demonstrate the effectiveness of people detection on the side of the bus and the haptic warning system in the steering wheel. The camera that detected the person was installed in the front (right) door. In the experiment, the driver turned the wheels approximately 40° to make a turn. Whenever the driver tried to accelerate, the warning mechanism was activated by the expulsion of the accelerator pedal and blocking the steering wheel to the right. This time, the right speaker emitted a beep, while the left speaker had no sound.

5 Conclusions

In this article, the developments made in the SAFEBUS project have been presented, related to an active safety system applied to public transportation vehicles. First, a system consisting of a network of smart cameras that can detect pedestrians moving around the bus has been introduced. This system uses image processing techniques that include various aspects such as detection of people by appearance and volume, in order to increase the robustness and reliability of the system. Such processing has been implemented in low-cost embedded devices which optimized code has allowed the processing up to 15 FPS.

A method for risk assessment of certain maneuvers has been developed considering pedestrians detected by cameras installed on the bus. Second, a set of haptic and audio-visual feedback devices have also been developed. Such systems can alert and make the bus driver aware of the danger of certain maneuvers. Specifically, its implementation consisted of the development of a haptic pedal, a steering blocking mechanism and an audiovisual interface.

In the study, the effectiveness of the safety system was demonstrated through two experiments carried out at the premises of Castrosúa SA. In these experiments, it was checked how the warning system alerts the driver and acts just in time when the vehicle performs a starting operation with danger or running over pedestrians. If this maneuver persists, then the emergency braking system is activated.

It is worth noting that the developments shown in this article are still at a prototype stage. Its implementation in real passenger vehicles will be carried out by performing a proof of concept to be developed in the coming months of 2016, enabling the production of an industrial prototype and the verification of compliance with the existing homologation standard for vehicles.

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Part IX
Training in Project Engineering

Implementation of BIM in the Subject Technical Industrial Projects—Degree in Industrial Technologies Engineering—University of Valladolid

Moisés Blanco Caballero, Patricia Zulueta Pérez, Ignacio Alonso Fernández-Coppel and Alberto Sánchez Lite

Abstract This study attempts to illustrate the current situation in the Industrial Engineering School in Valladolid regarding the development and management of engineering projects using the BIM (Building Information Modelling) methodology. It is widely accepted that the evolution of information modelling (BIM) is affecting the role of professionals in projects and in the management of the project life cycle. It is starting to become clear within the university environment, that the information modelling of BIM technology must become part of the education of future engineers. It uses integrated project delivery to respond to the professional demand that requires the development of skills in the educational practices to tackle the problems and limitations arising in the new practices. The BIM methodology covers everything from the project stage to asset management. The proposal of its inclusion in the Industrial Engineering School Degree qualifications came about in order to stagger the introduction of the student into the project process set up through this "new philosophy".

Keywords BIM · Teaching · Implementation · Modelling · Engineering · Projects

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1 Introduction

It is starting to become clear within the university environment that the information modelling of BIM technology must become part of the education of future engineers. BIM technology uses integrated project delivery (IPD), such that the professional demand and the approach of including these skills in the educational practices must tackle the problems and limitations arising in these new practices. In Spain, this methodology, both from a constructive and a pedagogical perspective, is not widely employed.

The overall objective of this study is to demonstrate the need for implementing BIM technology into study programmes of industrial engineering schools belonging to public universities in Spain. The BIM has been included for several years in universities elsewhere that are committed to the integration and training of professionals in this subject. To achieve this objective, this study focuses on the procedure and results of having implemented the BIM into the Industrial Engineering School at the University of Valladolid.

Firstly, a relevant literature review will be conducted of the existing research on the subject from different perspectives, obtaining a significant sample which will provide data on research carried out in other countries that support this paradigm shift.

1.1 What is BIM?

Building information modelling (BIM) is the process of creating and managing parametric digital models of a building (or a piece of infrastructure) during the building's life cycle (Mom et al. 2014).

There is no clear holistic approach or methodology to assess the adoption of building information modelling (BIM) technology at corporate level. Approaches are proposed for developing critical success factors that can be further developed for assessment of BIM adoption at an organisational level in the architecture, engineering and construction (AEC) industry (Tsai et al. 2014).

The BIM application not only provides solutions, which can be adopted and developed in other organisations and contexts that share similar challenges, but also provides knowledge on problems and bottlenecks of the application, necessary complementary tools and possible arrangements of the organisation (Miettinen and Paavola 2014).

Work methodologies and tools currently employed in the construction sector do not allow for changes to cope with market requirements. There is also no time for planning in projects that require more detailed specifications and productive efficiency is a struggle.

In the light of this, the development and application of production methods that favour multi-disciplinary and integrative work and collaboration between agents involved in the construction process is vital.

The BIM technology emerges as a response to the necessity to integrate all agents involved in the process during the different project stages (Patiño et al. 2014).

1.2 Uses of BIM

Work fragmentation is one of the key aspects of BIM, as well as the different locations of the participants and the different agents involved. However, with the advance in Information and Communication Technology (ICT), and in particular cloud computing, work fragmentation can potentially be overcome.

Cloud computing has become increasingly popular in recent years given that it continues to demonstrate the substantial advantages that it provides to the different users of this technology. These advantages are being widely discussed by many researchers and academics worldwide.

There are also risks in using cloud computing technology, security being the main concern. (Chong et al. 2014).

1.3 BIM Training Requirements

It is widely accepted that the evolution of BIM in the construction sector is increasingly affecting the role of professionals in architecture, engineering and construction (AEC) management and the industry (Wang and Leite 2014).

The construction industry and engineering programmes need to incorporate BIM courses that prepare their students with relevant BIM skills and knowledge, so that they are aware of the possible applications of BIM in their future careers in the construction industry and improve productivity. Students will also learn the importance of collaborating with interested parties in planning, as well as the inherent problems of BIM and its application (Ahn et al. 2013).

1.4 Inclusion of BIM in the Education System

The construction industry needs qualified engineers with BIM knowledge and skills, as well as the rest of professionals belonging to the AEC field.

A detailed set of 39 necessary topics for BIM competency in construction management, together with specific objectives for competency in each topic was recently compiled based on researching the industry's requirements.

A set of guidelines for integrating BIM topics into study programmes has been developed and tested by the Technion-Israel Institute of Technology.

BIM education interventions were planned in four of the seven courses, implemented and evaluated for three terms. The experiments showed that BIM must be introduced as a stand-alone topic, but most importantly, also as a tool for engineering tasks taught in design, analysis and management courses.

Knowledge of the social skills involved in exchanging information and managing knowledge, the professional roles and commercial context are also as important as the technological aspects (Pikas et al. 2013).

The Building Information Modelling (BIM) is becoming an increasingly common practice in the construction industry. Universities which offer construction engineering and educational management must include BIM concepts and skills in their degree programmes (Sacks and Pikas 2013).

Graduates in construction engineering and management today must have strong communication and teamwork skills, the ability to work efficiently with other teams working alongside them, and lastly, know how, to apply the principles of engineering, management and I.T. skills to their practice.

The introduction of BIM in a virtual collaboration environment allows teachers to design a course which includes the use of more realistic scenarios, better simulating the challenges of the real world.

Such experiences teach students how to undertake construction projects in practice, as well as how the different disciplines are based on other information, the type of information needed from relevant disciplines and when and how this information can be exchanged and shared among tools and processes (Becerik-Gerber et al. 2012).

Academics, through industry demand and participation, are starting to realise that in the education of our future engineers, the construction of BIM, which uses integrated project delivery, as well as collaboration and focus on design, have to be an educational priority.

As a result, the academic world is now burdened with the task of determining how to develop these specialised abilities in engineering students so that the professional demand and the focus on incorporating the appropriate skills in educational practices come together to tackle the problems and constraints that arise in these new practices (Solnosky et al. 2014).

Technological advances in the field of technical coordination and simulation provide new methods in BIM construction, which will improve the safety process, quality and last but not least, efficiency.

The lack of people able to work with comprehensive BIM is now one of the main barriers to using these technologies in architecture and engineering. The importance of improving this situation is not to teach students the BIM subject, but to ‘think BIM’ in all related disciplines (Fridrich and Kubečka 2014).

1.5 Objectives Sought in This Work

It remains to highlight what motivates this work and the specific objectives sought by carrying out the experiment explained below, which can be summarised by the following points:

1. The need to include BIM in the regulated teaching system in degree studies in Spanish public universities.
2. To open the field to studies and work carried out linking the academic environment and the professional practice: final dissertations in degrees, masters, etc.
3. To continue with the educational innovation of the European Higher Education Area, (EHEA): Promote group work, discovery of the autonomous potential of students, promote working in a network and with ICTs, multi-position cooperation, international cooperation, working with specialists, and incorporation into multidisciplinary teams, etc.

2 Background, Boundary Conditions, Context

The BIM implementation experiment has taken place within the University of Valladolid. The University of Valladolid is a public university with an extensive background given that it was founded in the year 1241 and its School of Industrial Engineering in 1913. The first School of Industrial Engineering was founded in Spain in 1850.

The degree in Industrial Technologies Engineering, in which the experiment was carried out, brings together knowledge of different technological areas of engineering (mechanics, electrics, electronics, automatics, chemical and organisation) in the industry. This solid and structured scientific-technical training is essential for modern, innovative, advanced and quality engineering.

This multi-functional and general training is required not only for large industries, but also for SMEs, which occupy a prominent position in the Spanish industry today. These types of technicians have a wide range of functions in specific areas such as research centres, R&D technology projects, in the implementation of emerging industrial technologies, and the development of other new technologies, as well as the participation in multi-disciplinary projects of industrial engineering. This qualification is a great incentive as a solution for the vast diversity and complexity of new problems which arise in modern industry.

Within the competences featured in the teaching programme in the degree qualification report is the competence and ability to design, plan, write, develop, organise, manage and lead projects.

These abilities require the student to be able to analyse the background, set the objectives, plan the work, select appropriate technologies, document and budget the

chosen solutions. This competence involves being able to define the scope of the project, specifying the technical characteristics and evaluating the economic-financial aspects and the economic, social and environmental impact of the project, allowing for the effective introduction of technical or environmental improvements in the future.

Currently, none of the industrial engineering schools in any public Spanish university offer BIM as a subject related to projects. At present, a BIM training is relegated to specialised courses, postgraduate programmes, talks, professional association courses, continuous professional development courses, courses in private training centres, etc.

2.1 Academic Context

The degree in Industrial Technologies Engineering taught at the University of Valladolid in the Industrial Engineering School is split across four years, with eight four-month teaching blocks, in which a total of 240 ECTS credits are taught, breaking down into 60 credits per academic year.

The module *'Industrial Technical Projects'* is included within industrial technology and is compulsory. It is worth 6 ECTS credits, 2.4 of which require attendance and the remaining 3.6 do not. It is taught in the fourth year, in the last four-month teaching block.

Prior to this, the student will have completed the *'Projects/Technical Office'* module which follows on from the *'Project Methodology'* module, a core module from the industrial pathway. This module is worth 4.5 credits, of which 1.8 require attendance and 2.7 do not. This module is considered the pre-requisite for the module *'Industrial Technical Projects'*.

The module *'Industrial Technical Projects'* acts as a connecting link and integrates all the knowledge acquired in the previous modules taken by the student in a teaching methodology that includes *Case studies, Exercise and Problem Solving, Project-based Learning* and a *Learning Contract*, combined with *Cooperative Learning,* given that the completion of the project by the student is carried out in groups of two.

2.2 Expected Learning Curve

The student starts off with knowledge which is mainly based on 2D skills, a likely result of their training in previous courses and compulsory disciplines, namely Graphics and Computer Assisted Design.

Therefore, a significant step is taken when faced with *'3D Models'* for the first time.

Once the model was created, the facilities were implemented, depending on the type of industrial facility planned. Subsequently by having models created, these same ones can be used again to detect intersections and geometrical clashes.

However, the real change, subject to the training within the projects/technical office module, is to arrive at an extended notion of what it means to employ *BIM,* and not focus on tools, in our case Revit®.

To implement this learning curve, different types of activities are carried out, depending on the stage at which the group of students find themselves, such as *Classroom lessons, Follow-up work in the Laboratory, Tutorials* and specific *Seminars*, above all in implementing the facilities into the model.

2.3 Expected Results

Once the experience is developed in BIM environments, it is expected that the students assimilate and acquire skills and knowledge on the following aspects:

- Knowledge of the life cycle of the project/construction/asset management/ demolition/end of life.
- Generation of BIM models.
- Incorporation of MEP (Mechanical, Electrical and Plumbing) facilities into the BIM model.
- Use of IFC ('Industry Foundation Classes') standards.

3 BIM Implementation Process

As previously commented, Building Information Modelling is a methodology which is carried out from the planning stage to the asset management, covering the whole life cycle of a building. In this case, its implementation in the planning stage is considered, through the use of certain tools and procedures that will be explained in further detail below.

The idea of establishing this methodology in the degree qualifications of the School of Industrial Engineering came about in order to progressively stagger the way in which it was introduced to the student in the planning process configured through this 'new philosophy'.

3.1 Implementation Stages

To achieve the established objectives, general criteria were provided for the formal elaboration of every technical project, as well as the requirements that had to have been included and the document structure.

The stages below were strictly followed:

3.1.1 Study proposal
3.1.2 From CAD to BIM
3.1.3 BIM tools and procedures for the project
3.1.4 Project process sequence and drafting manual.

3.1.1 Study Proposal

Taking into account the limited number of students taking the module (nine in total), it was proposed that a single project be worked on in a group with subgroups of two people working on the shared project. In this way, different users would have the chance to intervene simultaneously on the same advanced virtual construction model, making a base model and certain mini projects on structure and facilities. This way of working fed back the aspects that each student was working on into the overall knowledge of the group.

The scope of the project consisted in the execution of civil works (including heating facilities, electricity installations, sanitation, air conditioning and fire prevention) of a complex made up of office buildings and production premises for the manufacturing of cutting fluid filter machines. The work group decided on their geographical location based on requirements for size, orientation and necessary access to ensure the functionality of the building according to the purpose it would be used for. Likewise, an urban location analysis was carried out on the location selected for the purposes of building conditions. The programme of requirements to carry out in the facility was established jointly between the teaching staff and the work group and concerned both the manufacturing and the administrative area.

3.1.2 From CAD to BIM

The progressive implementation of BIM tools and procedures in the project stage was planned from the outset, starting with an introductory stage in which the student was familiarised with the criteria and way of working of this method, which, as previously commented, encompasses the project's life-cycle. A wide majority of students did not have the slightest notion of BIM until then and were expecting to undertake the work proposed in the module using traditional methodologies, until being introduced to the BIM tools, just recently becoming common in the project field. Therefore, the approach had to be modified by

changing the way of thinking about 'drawing' to thinking about 'constructing' in the use and subsequent management of the buildings, or in other words, from CAD to BIM.

3.1.3 BIM Tools and Procedures for the Project

Given that this teaching innovation undertaken in the 2013/14 academic year was a pilot experiment for the qualification, an accessible modelling program for the student was chosen as a starting point, which had a free educational licence. With this, they were able to design the parametric model of the premises, both geometrically and from the point of view of its facilities and structures. The program REVIT 2013 in Spanish belonging to the BIM Autodesk platform was chosen, which in a single application includes architectural design, construction, MEP engineering and structures.

3.1.4 Project Process Sequence

Once the students were aware that BIM was a fundamental vehicle for the project, the experiment started.

Firstly, the complex was designed and generally modelled with Revit 2013. The building, to be located in the technology park in Valladolid, would comprise two separate areas: rectangular production premises measuring 60 × 20 m, with maximum ridge height of 8 m with a gabled roof; and a square-shaped hub of offices measuring 15 m, two floors and fully glazed curtain walling. Both constructions were connected by a similarly glazed covered walkway.

At the same time, as they were modelling the premises, students wrote a log to clearly remember their own experience, which was finally used to write the manual to help students in subsequent years.

The group worked together on a single project in the design stage resulting in the architectonic BIM of the premises and its building annex, resolving the problems that were arising due to the novelty of applying the new methodology and, as previously explained, the change in the trend that came from having to progressively construct the building rather than draw it. In this way, in CAD systems, two parallel lines take on the meaning that the planner wishes to bestow on them: they can comprise an outside enclosure wall, an inside partition, a roof finish, a window frame or even power lines. On their own and isolated from their context, these lines are flat (2D) and lack any specific meaning. However, in BIM philosophy, each of the elements that is being included in the parametric model (3D) has its own identity. In this way, faced with the empty 'shell' of CAD modelling, a paradigm of data which comprises BIM was obtained (Fig. 1).

Once the object has been constructed virtually, the floors, elevations, sections, perspectives and renderings can immediately be viewed in 2D and 3D (Fig. 2).

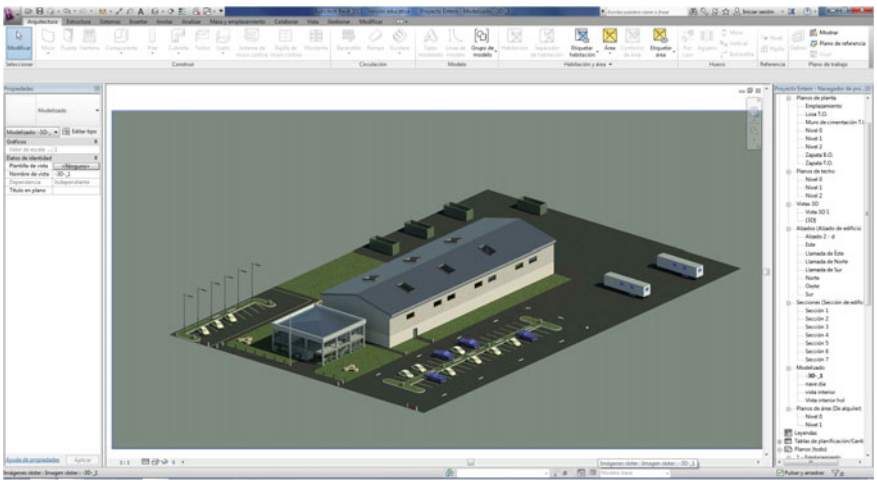

Fig. 1 Isometric perspective. Final result of the complex designed

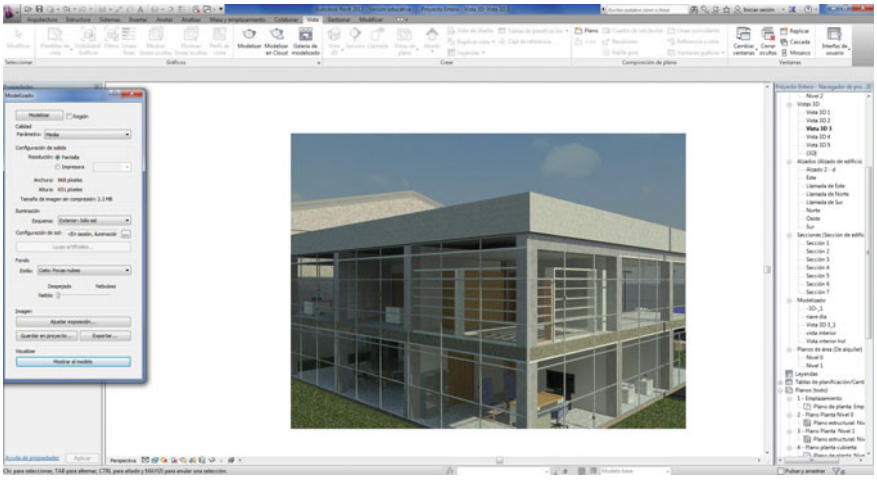

Fig. 2 View of the office building designed by the work group

It is important to note that during the entire planning process the teaching team followed their own educational methodology known as ACLS (Active Collaborative Learning System), which is the result of an exhaustive analysis and design of integrated strategies with additional pedagogical methods for the creation of a valid learning system that could also be applied to practical subjects in other areas. In this system, the student plays an active role in their own learning process, and the knowledge is acquired through group work, collaboratively, acquiring teamwork skills, independent learning, learning from other teams, decision

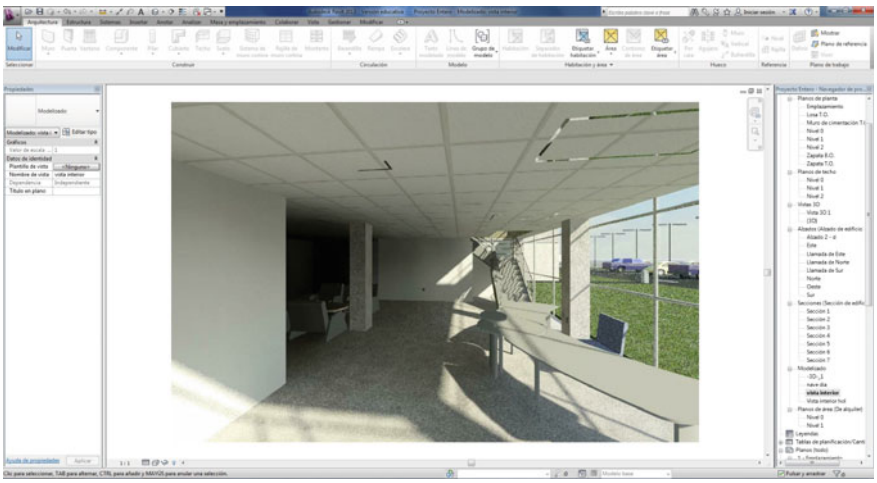

Fig. 3 Inside the office buildings designed by the work group

making, etc. The system also comprises analysing and discussing the work produced by different teams, offering these groups any relevant technical suggestions or constructive criticism. This methodology makes students feel that they are working to increase their general knowledge and improve their interpersonal relations, understanding that teamwork provides a series of advantages which would otherwise take more time and greater efforts to achieve. It is essential to also point out that this work methodology uses ICTs (such as the moodle platform or the cloud) to support the teaching activities, improving the quality of the educational process and facilitating the introduction into the classroom of procedures recognised by the European Higher Education Area (Fig. 3).

Continuing with the BIM implementation process and after obtaining the virtual architectural model of the premises, the following step was to divide the work group into two-person teams who would take on a sub-project linked to the base model, comprising the design and modelling of its supporting structure as well as the complex's facilities. The same program Revit 2013 would be used for this, but in its Revit Structure and Revit MEP applications. Starting with the initial architectural model, this work came up against considerably more problems than the previous stage and will be commented below.

The design and modelling stage was based on the following cases: the production premises would have a metallic structure based on HEB columns and metal trusses while the office building would be supported by a structure of beams and concrete columns 'in-situ', with the latter laid out in a 5 m × 5 m grid. In turn, the foundations would be carried out with isolated concrete footings under the column, linked by bracing beams.

While the modelling of the metallic structure of the manufacturing area was carried out quite effectively even with the setbacks of the analysis of the new Revit Structure module, the inclusion of the concrete structure was no easy task, producing

some unexpected results. Once the structural elements, columns and beams had been modelled, it was followed by almost manual placing of the drawbars, compression bars and abutments. Prior to this step, the family of reinforcements had to be loaded, given that certain elements were not initially available in the program. The families used in the project will be those present by default in Revit, other external ones or families created by the planners, in this case by the students.

After the complete structure, the geometric elements and its corresponding reinforcements had been modelled, the need for specific software to calculate the structure was clear, and the entire geometric modelling framework was exported from Revit. Once the results of this calculation were obtained, it could be implemented once again in the original model. This similarly occurred with the reinforcement of the footings and foundation beams.

In terms of the facilities' design, problems arose mainly from the fact that Revit MEP is not adapted to Spanish regulations. In the specific case of electricity, the instalment had to be reconfigured, redefining the voltages given by the American program and adding the necessary 230 and 400 V to the new configuration. A distribution appropriate for this use was also created, as well as another type of configuration from other parameters such as: cable sections, types of insulation, etc. Subsequently these elements, devices and planned electric equipment were positioned, adapting them to the new distribution system created previously (Fig. 4).

As with the modelling of the premises, the students recorded their experiences and subsequently included them in a new manual, in this case about electrical systems.

However, the most critical situation arose when undertaking the plumbing work. After unsuccessfully attempting to model in Revit, the team in charge of this area

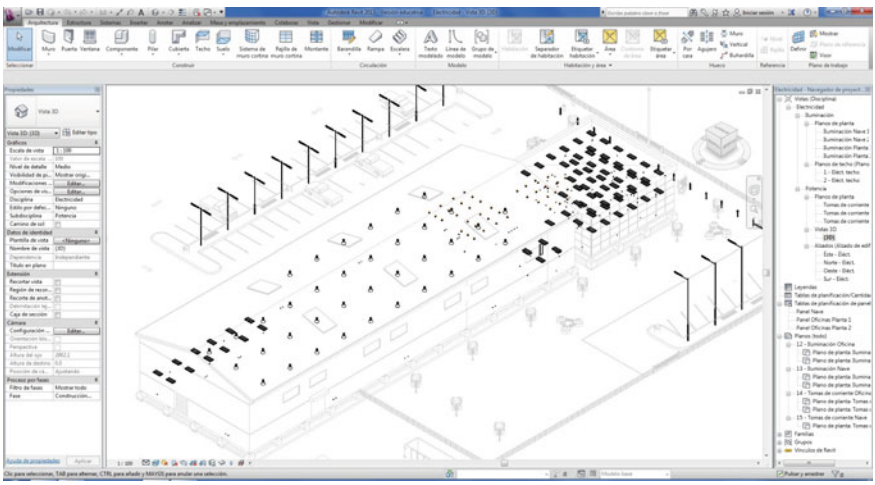

Fig. 4 3D view of the electrical facilities designed by a work team

decided to export the data to a 2D CAD program and continue the design of these facilities this way. This was due, in part, to the need to find solutions to be able to complete the project together and go on to present and deliver within the scheduled dates for the academic year. By doing so, the process initiated in BIM had 'fractured' somewhat, straying from the desired methodology. Seemingly a step backwards had been taken by returning to 2D, so distant from the BIM concept. Nevertheless, that was not perceived as a failure but as a new starting point in the staggered process underway. It also generated awareness of the BIM implementation strategy which should be considered as a way for new solutions to coexist in their early stages with 2D design applications. The stance of massively abandoning these applications was considered due to this fact, arriving to the conclusion that in the initial stages (or the PRE_BIM stages) it would perhaps be more practical to consider the possibility of importing/exporting to and from CAD. In that case, it is evident that while the implementation is underway, old systems should be withdrawn as they are clearly antagonistic.

Once the manufacturing premises and offices of the project and their facilities and structure had been modelled, the technical documentation was produced: report and appendices, plans, specifications, measurements and budget. For the measurements, Revit's planning tables were used through the management of data introduced in the project process. Lastly, the program Presto was used in the budget stage, which although is not BIM, can operate together with BIM applications allowing it to obtain the necessary information from the models to create the budget.

4 Results and Conclusions

The conclusions drawn from this study are, firstly, that there is a strong belief in the need to implement the BIM in university training for engineers in Spain. The educational community should move forward and put itself at the forefront where new methodologies are concerned, advertising and adapting itself to new technologies to train students on tools which they will be required to use in the professional world as is the case of the BIM.

Although the authors have been in very direct contact with the students, many problems were detected when understanding and handling the programs which, contrary to what was first expected, have substantially delayed the process.

Overall, the experience has been satisfactory and the authors are encouraged to continue its development. In this way, it is evident that the following stage of the BIM implementation process should comprise the calculation of all that was pre-designed in the modelling stage, using specific programs both for installations and structures.

Although the students have demonstrated their involvement from the start, the authors have detected that greater awareness of BIM is needed on all levels in the project field in Spain.

Once the study was concluded, all participants in the experiment were fully aware of the need to implement BIM within the study programmes of engineering in the public university, which is currently more in demand in Spain.

The students' teamwork has proved the need for the awareness of working together and to develop skills in coordination, leadership, negotiation, motivation and communication, all required by the current labour market.

Resources and support are needed within the university system for BIM to be implemented. Universities should promote this implementation, training staff and students, attending training courses, creating BIM knowledge training days, etc. A BIM culture within the education system must be created.

The students have gained awareness of the immediate importance of the use of BIM for the future development of their careers. This is an unstoppable phenomenon, so it is important to adapt to it sooner, to avoid suffering the consequences of compulsory implementation on an international scale.

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Technological Immersion in Industrial Engineering for a Project Management Course to Develop Dual Use Technology

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Abstract Technological Immersion (TI) is defined as an approach process to current industrial activity. It is focused on improving the competitive standards of the production activity by analyzing innovation processes, which were regulated by any standard that summarizes most of the international and relevant knowledge on Innovation Management Processes (for Spain, this is the regulation UNE166000). It allows using education on Project Management as a basic foundation to develop dual use technologies for security and defense purposes and for any other industry framework as well. The aim of this case study is to compile, under a TI scope, the experiences acquired by the students of the fourth course at the University Centre of Defense at the Spanish Air Force Academy, when studying the last generation of films that may have high strategic interest for defense as well as for many industrial applications. The TI was performed through a workshop about UNE166000

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(Spanish Regulation), McLuhan Tetrad and other lessons on Innovation Management, the main purpose being to teach the students how to draft a professional report about the technological and knowledge transfer opportunities that these films may generate in order to develop new industrial advantages on dual use industry.

Keywords Technological immersion · Project management · UNE166000 · Dual use technology

1 Introduction

Most of the Professional Project Management (PM) courses aim to teach students some specific guides and standards to use a common language, in order to reach full success when a new project starts. This process seems to be hard to handle for students when they need to open up their minds to theory lessons to face for the first time an approach to real Knowledge Management (KM) processes.

This case study resumes the experiences collected from the author's professional background and from the subject "*Proyectos de Ingeniería de Organización Industrial*" taught at the University Centre of Defence for the Spanish Air Force Academy. In this course, students often start with a relevant question about the subject: "How will we be able to apply this knowledge to a real working situation?".

The teacher's answer is the same year after year: "*You must find the answer in Technological Immersion*".

Technological Immersion, therefore, is a powerful tool to create new project manager competences for students in relation with KM processes that bound together research, innovation and development. As an example, when students are handling technological frontline products before any other user, an innovation cycle starts, and they acquire a positive attitude towards PM when they realize it is a very strong essential tool to use in their professional life.

The case study involves students whose future working frame is entirely focused on the Defence and Security field for the Spanish Air Force. Nonetheless, while these students will need to acquire the knowledge required by the Defence and Security Industry, the same process can be extrapolated to other circumstances in which KM is required to enforce any other industry facing a competitive environment where a continuous improvement cycle is needed for innovation.

2 The Defence and Security (D&S) Industry as a Framework

There are many definitions of D&S available, but the most appropriate for teaching purposes, due to its wide scope is:

D&S Industry is the result of gathering several providers of goods and services who meet the Armed Forces demands for equipment as well as intangible assets. This equipment and assets have been more recently destined for civil applications in what is called "dual use" technology: equipment, knowledge (Lancho de León 1999).

Under this concept, the stakeholders involved may be able to identify some singularities of the D&S market and industry, where the knowledge processes take place and in which the student framework is enclosed. These singularities are:

- The market is characterized for being a monopoly on the demand and an oligopoly on the supply.
- Goods and services require high technology design, which raises the price of the chain-value.
- Public founding is highly involved, working as a driving force for this industry R&D.
- Asymmetric management processes, where the government customer forces the demand but does not have any influence on the prices of goods and services.
- The security standards that protect the information and the know-how developed insulates this industry from other industrial activities or dual use applications that could display new financial inputs and, therefore, enforce the S&D Industry. These entrance barriers, which are set up in the beginning, will become exit barriers to outer markets.

In relation with PM, the course was designed to align this framework with the students' point of view by focusing on dual use technology to make a breakpoint on some of these singularities. So when the students create some both-way transfer processes, the results show how PM tools improve at the same time the D&S Industry and other Industries.

The course also leads the students to analyze the most common innovation models as an approach to improve the competitive standards of the production activity through Organizational R&D&i Management processes. These processes become management tools to improve the competitive standards of enterprises of any size (López et al. 2009).

The innovation models just mentioned have been widely analyzed and classified as linear, step, interactive, integrated or net models (Zamanillo Elgezabal et al. 2007). All of them are summarized in the Kline's model that makes reference to the most common stage model or chain-linked model (Kline and Rosenberg 1986). This model is still used as a reference inside the European framework and, thus, in the Spanish convergence regulation process (see Fig. 1) developed in 2013 by standards UNE-166000 in order to propose a valid model to manage R&D&i (AENOR 2013).

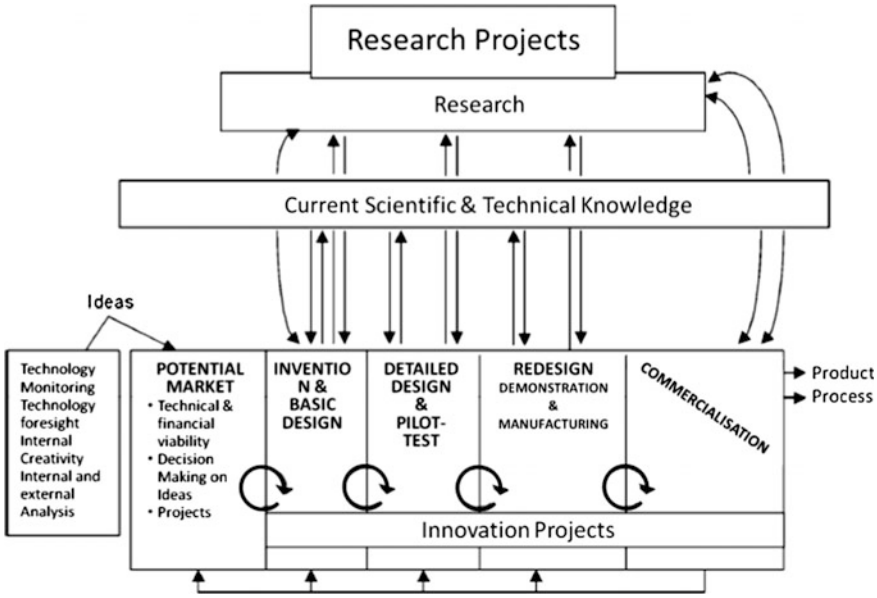

Fig. 1 R&D&i Kline model in the Spanish standard UNE166002 for management system requirements

Regarding the R&D&i, the Spanish Public Administration offers several management improvement programs to help some organizations increase their opportunities to survive in today's global market. Those programs follow the Kline model and its seven stages are described as follows:

1. The Linear Process. Any new idea starts a sequence that begins at the expected market study and ends when the innovation is commercialized.
2. Internal Feedback Process. The feedback between two closed stages tries to solve any undesirable deviation from the base line projected.
3. General Feedback Process. As a general guarantee to improve the final result.
4. The Scientific and technological Knowledge interaction. The knowledge background allows the organization to move from one stage to another and if this one is not enough, then a new research process tries to develop it.
5. Both way process. Research & Innovation works to force the market into what is called a "Technology Push" strategy.
6. Relational process. Marketing analysis and Research may provide specific solutions to solve market problems.
7. Cycle Innovation process. Firstly, the organization has to watch the market; the next step is to focus on market problems, so all the stakeholders probably will need to get a specific training to increase their capabilities; the next step will set up all the needed actions. The cycle ends with a lesson learned process to increase the organization knowledge.

2.1 The Innovation Process

Current communications technologies for networking configuration allow to take advantage of the KM processes (Novelli and Pincolini 2005) and in a specific way, of the scientific and technological knowledge involved in the R&D&i process. So there are already several ways in which the networking is being used to earn profits. Some of these ways are: collaborative learning networks, virtual networking environments, networking for educative ecosystems, design thinking through networking, networks for ontology development.

Other examples of networking may be extracted from the work of some relevant authors to reach goals that require several disciplines from the organizational structure in order to take advantage of the organizations cognitive qualities by focusing on its creativity and communication abilities (Chibás Ortíz et al. 2014). Nevertheless, these processes according to these authors must be planned, taking the technological and methodological knowledge of the organization into account to force the working teams to engage in a cooperative strategy in order to reach the desired goal.

Under these criteria, the "Design Thinking" networking may be a useful tool as a previous strategy to create the foundations of a collaborative system applied to KM (Hernández Sellés et al. 2014). Design thinking resumes a communication strategic process (Hasso-Plattner-Institut 2009) at (Steinbeck 2011) inside the organization framework in which the next sub-process will be found:

- Understand. This process requires the organization to acquire all the ontological knowledge regarding the matter of study and, after an internal organization process, understand the circumstances and the minimum concepts needed to guarantee a deep learning of the knowledge dimension about the case study.
- Observe. By this process the organization extrapolates the knowledge from other enterprises or governmental institutions where it was used or could be used to solve a similar organization need. This is a reflexive process that requires the understanding of the organization needs and other dominion analysis capabilities.
- Define Point of view. Each working group will focus on its own resources according to the knowledge areas they fully understand and will provide solutions linked to these strengths.
- Ideate. This is the creative process in where all solutions considered are interrelated with the strengths of the whole group to provide specific solutions to the organization needs.
- Prototype. This is the first real approach to the solution that satisfies all the technical or conceptual specifications extracted from the previous process and that will be validated in the next step.
- Test. This process validates the proposed solution by testing all the models, prototypes, etc. and finally by receiving the formal communication of acceptance by the final user.

2.2 McLuhan Tetrad Applied to R&D&i Improvement

Regarding media theory, there are several references to one of the most famous communications study authority, Marshall McLuhan, who published the laws of media in 1989 and who stated the foundations of what is currently known as the information era. According to those foundations, McLuhan designed the tetrad (see Fig. 2) to provide a scientific basis for media observations (Verstraete 2011), but the tetrad itself is an important contribution to any field where new ideas must be developed to innovate.

The tetrad was drawn up through four main questions defined as follows: (Ferderman and De KerKchove 2003):

- What does the medium enhance?
- What does the medium make obsolete?
- What does the medium retrieve that had been obsolesced earlier?
- What does the medium reversal or flip into when pushed to extremes?

These tetrad vertexes have been explained thoroughly by some relevant researchers (Hempell 1996) and reoriented to innovation subsequently (Sameshima 2006) in order to redefine them as follows (Verstraete 2011):

- Enhancement as "the amplification of effects" with a "focus on the practical". It involves the "creation of vortices of power" and presents a "solution to previous problems".
- Retrieval as "the recovery of values and insight" previously "lost or eroded". It can involve the "transition of ground to figure"; that is, the movement of a phenomenon from the periphery to the centre of attention.

Fig. 2 Mcluhan´s Tetrad. (Mcluhan and Powers, 1989)

- Obsolescence as "the erosion of formerly significant artefacts". This reverses the transition above causing a "transition of figure to ground" in which some previously important phenomenon is moved to the periphery.
- Reversal as "the reverse of enhancement; the unexpected dissatisfactions. Pushed to its limits, the artefact flips on its user" and creates new problems.

These definitions allow reformulating the four questions in order to enforce the design thinking processes when it is applied to R&D&i, which is one of the main goals for the PM course in this case study. Therefore, the final questions used were the ones mentioned by Verstraete, which are:

- Enhancement: "What does your new idea improve or enhance, make possible or accelerate?"
- Retrieval: "What earlier obsolete idea/innovation/tool brought back into play becomes an essential part of your new idea?"
- Obsolescence: "What idea/innovation/tool is obsolesced by your idea?"
- Reversal: "When carried to full potential, your new idea will reverse its original characteristics, what would be the potential reversal of your new idea?"

3 The Case Study

In order to achieve the goals of the Professional Project Management (PM) course for the Spanish Air Force Students (70 students divided in two sections, A and B), the teachers designed a technology immersion experience, which followed a real approach where the student could be in a professional meeting for two hours with one of the most advanced manufacturer of high-tech films (see Figs. 3 and 4), and even touch several products that are not yet commercialized.

Novogenio SL is a leader enterprise with unique research resources in the European Union, with highly trained human resources that allow this company to provide high technical solutions to current tough industrial problems in the field of impact and abrasion protection, insulating, conductive plastic, photovoltaic applications, development and others possibilities.

The students were given the assignment of drafting a professional report about the meeting as a real approach to what the innovation analysis for future development may require in their future framework.

Fig. 3 Students at the TI while they handle some films applications

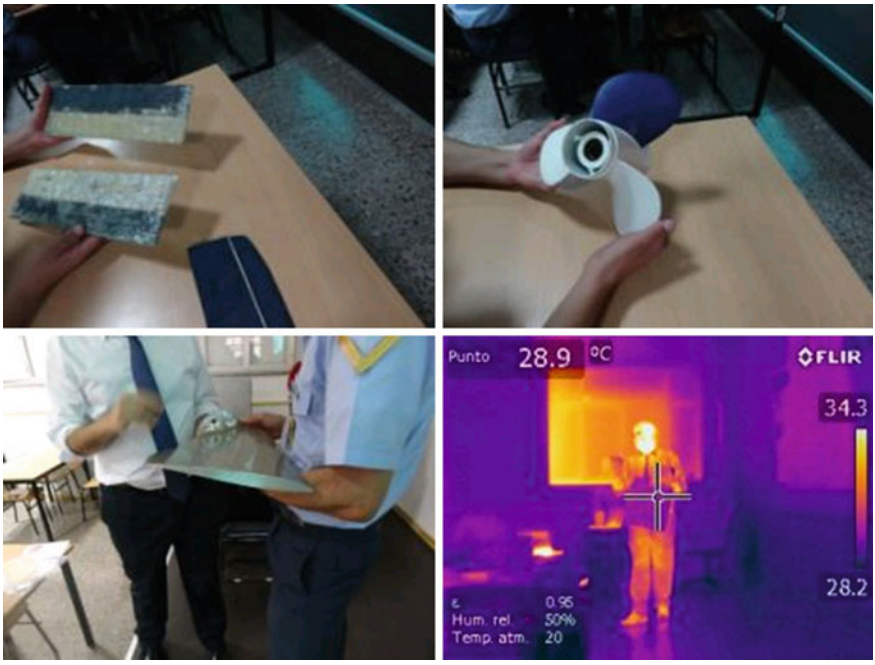

Fig. 4 Students identified some of the possible applications

3.1 The Exercise Statement

The Technology Observatory and Research Service request your expertise to evaluate the level of technological innovation of the last generation of high-tech films. After a large survey you have been assigned to meet with the head of research of an advanced innovation enterprise, Novogenio SL, to collect all the information that may be considered of interest for the Spanish Defence Governance to enforce the Security and Defence Industry.

Novogenio SL, using their own design infrastructure manufactures Technical and Optical films for different Industrial sectors: Photovoltaic, Wind, Glass, Electronics, Transportation, Aeronautics, Defence, Textile and Printing. Among Novogenio's products any customer may find:

- Optical films used in photovoltaic's modules, through the EVA Nosolorar design to satisfy the hardest customer specifications.
- Optical films to manufacture all security glass products. Bullet proof included NovoGuard and EVA NovoGlass.
- Outstanding films used in coating processes to protect all kinds of surfaces.

Novogenio SL has developed a wide experience in R&D&i and owns several international patents (see Fig. 5) related with coating and sputtering processes that push the market to a new technical era in film technology.

3.2 The Students Report

In order to learn a useful PM standard in relation with innovation, the students of sections A and B were divided into smaller groups of no more than ten members

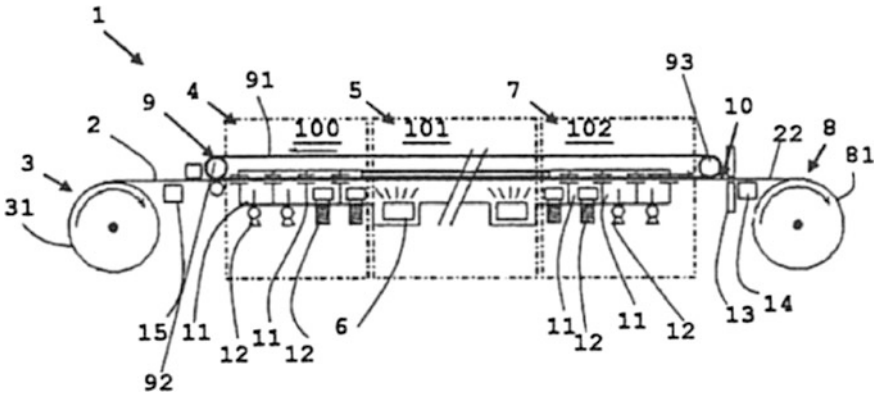

Fig. 5 Example of the design of Novogenio international patent #PCT/EP2008/060278

(see Fig. 6), to compose a professional report following a common R&D&i standard report with the next main sections.

Standard Report Index (the innovation report may follow the next sections)

1. Aim of the report. (Describe who requested the report and its main goal)
2. Scope Statement. (Describe the lowest level for the Scope decomposition)
3. Short Organization Description. (Describe the provider's technological capabilities)
4. Meeting Briefing. (Describe the main notes from the meeting)
5. Possible D&S Applications detected and their McLuhan Tetrad. (Develop the most relevant applications detected)
6. Final Factor Weight Analysis. (Apply a weight matrix to evaluate the different applications detected. As an example, see Table 1)

Fig. 6 Working group in discussion after the immersion

Table 1 Weight factor matrix

Factors	Relevant questions to be answered	Value	Weight
Maturity	How many competitors are involved in the technical innovation evaluated?	[1–5][1]	%
	How many alternative goods or services can be found?	[1–5][1]	%
	How often do you consider that the goods or services developed should be updated?	[1–5][1]	%
	(Develop some more questions of your own)	…	…
Suitability	To what extent do you consider that the technical innovation is suitable to be applied to the Air Force needs)	[1–5][2]	%
	(Develop some more questions of your own)	…	…
…. (Develop also some more Factors)			

[1][1-Too few…5- Too many] [2][1-First grade…5-Insignificant grade]

4 Conclusions and Future Works

The course ended and the students successfully met the course goal by delivering a final report and a survey where they answered eleven questions (see Table 2) that provided the students feedback and the course evaluation between 0 and 5 points. The applied scale assigned 0 for bad evaluation or not in agreement with the question, and a 5 for the best evaluation possible or when the students fully agreed with the question.

The survey results (see Fig. 7) reported a higher score for this course than the average of the student's evaluation for other courses at the same university; the success of this result being focused on the student transformation from a passive attitude to an important and active role in the learning process.

The students developed new innovation skills and competences, which was one of the most important goals of this PM course. As a matter of fact, Novogenio SL was selected recently by the Spanish Ministry of Defence, as one of the most interesting enterprises to be considered for the "Programa Coincidente", which is the Spanish Defence cooperation program to develop R&D&i in the field of Security and Defence (DGAM 2015).

Future works on next courses are taking into consideration similar technological immersion experiences to design new examples, which may help the students develop new competences in relation with real professional practices, more specifically a TI in flexible printed electronic circuits. Thanks to Vivainnova Lt. Printed, electronic circuits seem to be an emerging innovation for applications in the D&S industry and also civilian industries.

Table 2 Feed-back questions

#	Question description
P1	Teachers' attitude in this course promote the students interest in the subject
P2	Teachers' expositions were clear and fully understood by the students
P3	The e-learning media was well configured and was useful for the students
P4	Teachers promote co-working and invited the students to participate actively
P5	Teachers provided several tutorials classes outside the course schedule
P6	The results provided by the teachers during the course allow to improve the students grades
P7	The activities scheduled to be accomplished outside the course schedule are useful for the students learning process
P8	The teaching methodology helps the students develop new knowledge and competences on the subject
P9	The evaluation methodology was clearly exposed and it was appropriated for the subject
P10	As a student, I felt during the whole course that I was developing the competences stated in the subject syllabus
P11	In an overall view of the subject, as a student I am fully satisfied with the work developed by the teachers

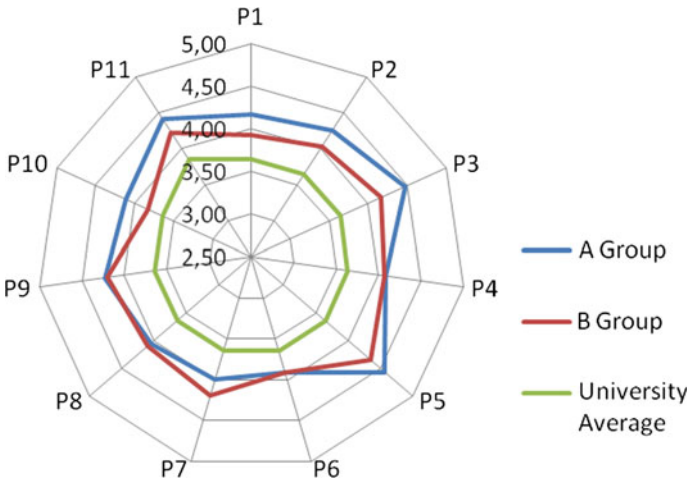

Fig. 7 Students feed-back

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Quantitative and Qualitative Analysis of Project-Based Learning to Acquire Competencies in Project Management

Dante A. Guerrero Chanduví, María del Carmen Barreto Pérez, Catherin Girón Escobar and Diego Saavedra Agurto

Abstract The workplace is increasingly demanding when hiring professionals as project managers, with a certain professional competence development level specific to this area. Universities and professional training centres face the challenge of applying learning methodologies that will facilitate the development of such competences. The aim of this communication is to rigorously analyse the students learning process, through a mixed evaluation methodology (quantitative and qualitative) applied to project-based learning methods, on a course that combines PMI (Project Management Institute) and IPMA (International Project Management Association) models. At the beginning, a statistical analysis of the evaluations results (objective tests) was performed. Afterwards, and based on these results, a qualitative analysis of the reports content was completed. Based on the specialized bibliography, a categorization of the results was achieved, to assess the evidence of how students have improved those competences during the learning process. As a result, this research will allow a diagnosis of the learning methodologies applied and how they contribute to the acquisition of competences by the student.

Keywords Content · Analysis · Professional · Competencies · Skills

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1 Introduction

Currently, professionals (mainly Project directors) are required to have a vast experience, to be able to find quick and varied solutions to problems, to show an open attitude towards different opinions and perspectives and to develop professional competences. The best way to achieve this goal is by facilitating the acquisition of knowledge, skills and competencies necessary for the accomplishment of effective professional work in a certain area.

Therefore, it is very important that a high-quality education system ensures that, at the end of their learning process, students have achieved a better understanding of the professional competences needed to meet market requirements (Hansen 2004; Palma et al. 2012; Shuman et al. 2002; Smith and Prados 2000; Sunthonkanokpong 2011).

This paper shows the impact of the Learning Based on Projects methodology for the improvement of professional competences in Project Management. Competences with the highest degree of development are identified through a quantitative analysis and the possible causes of their development are detected, using a qualitative analysis. The analyses were based on the results of the Projects courses taught at the Universidad de Piura from 2011 to 2014. Section 2 contains an overview of the PBL methodology and the competences required for project management according to IPMA. Section 3 describes the Projects course features that are posed as a case study. Section 4 introduces the methodology followed in this paper. In Sect. 5, the analysis results obtained are presented and, finally, in Sect. 6 the conclusions of the investigation are highlighted.

2 Learning Based on Projects and IPMA Competences

Project Based Learning (PBL) is a didactic learning model centered on the student. In this methodology, students are provided with the opportunity to be part of a way of learning very close to real situations, making them responsible for their own learning. It means forming teams integrated with people with varied profiles, so they will be acquiring, using and applying concepts of the course that they will be discovering throughout their investigation. Moreover, they will be developing planning, problem-solving, design, organization, implementation and project evaluation abilities.

It also helps them to develop competences like self-learning, communication, self-reliance, commitment and motivation, teamwork and crisis management, and it provides graduating students with a high level of experience and academic performance (Galeana 2006; Harwell 1997; Martí et al. 2010; NAF 2011; Remziye Ergül and Keshin Kargin 2013; Thomas and Mergendoller 2000).

In this methodology, the role of the teacher and/or monitor is very important, given that he/she will be in charge of providing support, including academic

resources facilitation, learning orientation, the acquisition of key competencies, feedback, good practices and encouraging the student to commit to their project (Bell 2010; NAF 2011).

The PBL structure can be defined in 4 parts: information gathering, planning, implementation and evaluation. In the evaluation phase, self-evaluation is included to help students reflect on their level of competence at the beginning and at the end of the course, and to reflect on their performance in the project in every area (Bell 2010; Miguel Díaz 2006).

A significant addition to the PBL methodology is the development of Project Management competences defined by the International Project Management Association (IPMA). This addition allows the connection between higher education and a professional certification system, which opens a lot of opportunities for the students in the future (De los Ríos et al. 2010; Guerrero et al. 2013).

IPMA develops three competence dimensions: technical, behavioral and contextual. In these three dimensions, there are 46 professional competences (20 technical, 15 behavioral and 11 contextual) that are requirements for a person to act in a correct and transparent way, so as to benefit any project, program and portfolio, thus satisfying stakeholders expectations (IPMA 2009).

Technical competences describe the necessary elements to put a project in place, manage its execution and close it. The behavioral ones describe the commitment and motivation of the project director, as well as their attitudes and skills. The contextual ones describe the concepts of the project, program and portfolio and the link between these concepts and the organization or organizations involved in a project (IPMA 2009).

The IPMA World Certification System proposes its model at 4 levels: A, B, C and D. The certification al Level D is of "Technician in Project Management". In this case, practical experience in the elements of competence in project management is not mandatory, but it is necessary to have the knowledge about all the elements of competence in project management. The study is focused on this level because it is adequate for the way the analyzed courses have been developed. To be certified at level D, it is necessary to demonstrate knowledge in 70% of the technical competencies, 15% of the behavioral competencies, and 15% of the contextual competencies. A person certified at that level is capable of applying his/her knowledge in project management when participating in projects of any size, in a sufficient level to perform their function (IPMA 2009).

3 Projects Course

The main purpose of the Projects course is to offer the students the methodological tools, within the body of knowledge of the general theory of the project, and the optimal development of professional competences in Project Management.

The course was designed based on the "*Bases para la competencia de Dirección de Proyectos NCB Versión 3.1*" (IPMA 2009) (Foundations for the competence in

NBC Project Management, Version 3.1) and the "*Guía de los Fundamentos de la Dirección de Proyectos 5ta Edición*" (Guideline of Foundations in Project Management, 5th Edition) (PMI 2013).

3.1 Course Assessment

The assessments performed during the Project course are classified into three types: exams, the Semester Project, and participation.

Exams are carried out virtually through the MOODLE platform. The questions are multiple choice. They are prepared following the characteristics of the written exam for level D® IPMA, and they are classified according to the competence codes. Exams represent 20% of the total evaluation.

The Semester Project is developed in groups, with a maximum of 5 students per group. The students are free to organize themselves in groups and to choose the project's subject. Each group is assigned an IPMA Project Management certified monitor, who answers questions about the course content and provides advice in project management. The approval of the Project is a condition to pass the course. The evaluation is based on criteria, the formative aspect, is directly related to the main deliverables and represents 20% of the total evaluation.

Participation is continuous, directly related to participation in workshops, in the project, the meeting of formal evidences of competences acquisition and the formal presentation of the deliverables: Articles of incorporation, Statement of the scope, Management plan of the project I, Management plan of the project II, Management Planning and closing report. Participation represents 20% of the total evaluation (Guerrero et al. 2014).

4 Methodology

The research questions were the following: "which were the competences that students in the project course developed the most?", and "how were they able to do it?" For that, two analyses were made, one quantitative and another one qualitative. For the quantitative analysis, the historical record of the years 2011, 2012, 2013 and 2014 of the Projects course were taken as a baseline, and for the qualitative analysis, only 2014 was considered as a baseline. As the pattern of the competences repeats every year, the causes of its development in a particular year can be searched. In this case, it was convenient to utilize data from the most recent year, 2014.

The *quantitative analysis* was used to find out what competences were developed the most in the projects course. This was done based on the student's perceptions and statistical tools such as T-tests were used to evaluate significant variations, and bar and circular graphs were used to process and show results.

For this analysis, Microsoft Excel 2010 and STATGRAPHICS CENTURION XVI tools were used to be able to perform the statistical calculations.

Having 46 competences in the 4 years of the students' self-assessments, a filter was first applied that consisted of performing T-tests of paired samples from the final and initial results to see what competencies had improved significantly each year. For the T-test of paired samples, the equality of means was taken as the null hypothesis, which is rejected if the significance level (p-value) is less than 0.05. After that, the T value was analyzed, and for that the following equation was considered:

$$T = Md/(Sd/\sqrt{N}) = (Initial - Final)/(Sd/\sqrt{N}) \quad (1)$$

where T is the statistical value, Md is the mean of the difference, Sd is the standard deviation and N is the size of the population.

If T is negative, it means that the subtraction of the initial values minus the final values is negative. Therefore, there was an improvement of competences. If T is positive, it means the competences worsen.

After having applied the first filter, a second filter was applied to identify, from all the competences that had a significant improvement, the ones that had a greater percentage of improvement, that is to say, to do a "top of the competences" that developed the most each year. For the technical competences, a top 10 was chosen and for behavioral and contextual competences, a top 3 was chosen, to maintain the proportion of knowledge a person must demonstrate to be certified in IPMA level D (if 10 represents 70%, then 15% is 3). Then, the top competences for the 4 years were compared, and competences that were repeated in the four years were identified, obtaining a list of competences to be analyzed.

For the *qualitative analysis*, once the competencies to be analyzed were identified, the next step was to find out how students developed them. To accomplish this, the three types of assessment developed in the courses and the self-assessments were analyzed.

These qualitative analyses were performed in three ways, due to the nature of the competences involved. Technical competences were analyzed through the documents and reports that students worked on and delivered during the management of their projects. To analyze behavioral competencies, judgments from experts, experiences from researches, monitors and students were reviewed. Finally, for contextual competencies, the percentages of progress through written exams were analyzed.

The AQUAD 7 software was mainly used in the qualitative analysis of technical competencies, to identify improvement patterns. Values can be entered into this software (in this case, grades) to identify patterns and then analyze them. In Table 1, an example of how this software works is shown.

In Table 1, an example of 5 students and their exams average grades (grades go from 0 to 20, with passing grades 11 and up) in the management plan and their final

Table 1 Example of data used in AQUAD 7

No	Full name	A	B	C
		Average exams	Plan for management	Final project
1	Student 1	10	18	14
2	Student 2	14	12	18
3	Student 3	13	14	15
4	Student 4	11	17	18
5	Student 5	12	17	17

Source Prepared by the authors

Table 2 Example of the true table returned by AQUAD 7

No	Full name	A	B	C
		Average exams	Plan for management	Final project
1	Student 1	0	1	0
2	Student 2	1	0	1
3	Student 3	1	0	0
4	Student 4	0	1	1
5	Student 5	0	1	1

Source Prepared by the authors

Project. This data is entered into AQUAD as a table. Then, the software will transform this table into a true table. AQUAD 7 chooses the ranges of values to which 1 (positive) will be assigned and the values to which 0 (negative) will be assigned. The researcher can also choose those ranges according to his own criterion. This is seen clearly in Table 2, which is what AQUAD 7 returned after this command.

As can be seen in Table 2, in the average of exams grades, AQUAD assigned 1 to all values greater than 13. In the management plan, it assigned 1 to all values greater than 16, and finally, for the final project, it assigned 1 to all values greater than 17.

Once the true table is obtained, AQUAD 7 can identify all the patterns. The researcher can establish which main criteria are to be considered. In this case, the criterion was that all the students have had excellent grades in their final project, or in AQUAD 7 terms, that the grades of the final project are 1. The software will provide the following patterns (see Table 3).

Table 3 Patterns present in the AQUAD 7 examples

Patterns	aBC	AbC
No of cases	2 cases out of 5	1 case out of 5
Cases	Student 4, Student 5	Student 2

Source Prepared by the authors

Capital letters represent the 1's and the lowercases the 0's. As can be seen in Table 3, AQUAD 7 shows the patterns that appear if C is always 1, the number of cases that has this pattern and what elements meet that pattern.

In the case of the example, most of the students who were successful in their projects, had also been successful in their management plan. Patterns found through AQUAD 7 will be explained in the Results section.

5 Results

5.1 Quantitative Analysis

From the historical analysis of the 4 years and the T-tests, the obtained competences can be seen in Table 4. Nine competences will be analyzed: 7 technical, 1 behavioral and 1 contextual.

To obtain a better general idea of competences development, the comparative of self-assessments against the written exams is shown, for the three groups of competences, for the 4 analyzed years. For this assessment, a T test of paired samples was also performed. The historical results of the comparison can be seen in Table 5.

In Table 5, in the initial situation as well as in the final situation, for the 4 years analyzed it can be observed that the *p*-values have been less than 0.05, which indicates that the null hypotheses from all these years and from all the groups of competencies are rejected. Also, all the T values are less than zero, which indicates that, both in the initial situation, and in the final situation, students had a slight pessimistic perception of themselves by perceiving that they did not improved much when they really did.

The only exception was on the year 2012, in the final situation of behavioral competences, where the difference between the results of the final self-assessments and the final exams were pretty similar.

This analysis indicates that students are even better (or in the case of 2012, the same) than what they perceive, confirming it is correct to use the results of the

Table 4 List of competences to analyze

1. Technical C.	2. Behavioral C.	3. Contextual C.
1.01 Project Management Success	2.12 Conflicts and crisis	3.01 Projects orientation
1.02 Stakeholders		
1.03 Project requirements and objectives		
1.06 Project organization		
1.09 Project structure		
1.10 Scope and deliverables		
1.20 Close-out		

Source Prepared by the authors

Table 5 Results from T test in the last 4 years

Sections to Assess	Competencies	2014		2013		2012		2011	
		p-value	T	*p*-value	T	*p*-value	T	*p*-value	T
Initial situation Ai = Ei	Technical	2.86E−9	−7.60	0.00	−11.9	0.00	−11.3	1.52E−9	−7.60
	Behavior	9.20E−7	−5.80	1.37E−4	−4.13	8.98E−3	−2.69	3.72E−3	−3.06
	Contextual	1.40E−11	−9.32	0.00	−11.1	2.53E−3	−3.14	0.00	−11.0
Final situation Af = Ef	Technical	1.00E−5	−5.05	5.36E−10	−7.64	3.44E−7	−7.13	3.71E−9	−7.33
	Behavior	4.22E−11	−8.95	6.79E−7	−5.90	0.39	−0.86	1.12E−9	−7.69
	Contextual	1.03E−8	−7.19	0.00	−10.79	3.91E−7	−5.89	1.35E−11	−9.04

Note: *Ai* Initial self-assessment, *Af* Final self-assessment, *Ei* Initial exam, *Ef* Final exam
Source Prepared by the authors

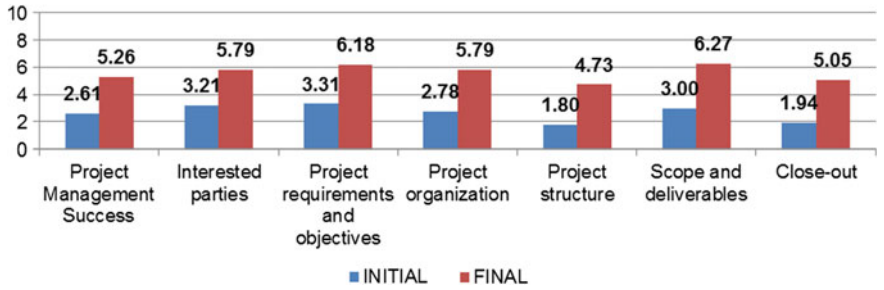

Fig. 1 Average historical scores of technical competencies. *Source* Prepared by the authors

perceptions of students for the selection of competences that are developed the most in the projects course.

In the historical analysis, the 9 chosen competences can be observed in the 4 years, beginning with the 7 technical competencies. This can be seen in Fig. 1.

When comparing for each competence, the initial situation against the final one, through the 4 years, it can be observed that students perceived a great improvement of their technical competencies because their scores increased in great proportion.

For behavioral and contextual competencies, it is convenient to show in percentage how students grade themselves in their self-assessments. First, the competence of behavior "Conflict and crisis" will be analyzed in Fig. 2.

Big variations in the initial and final perceptions from students are observed. Most of them (56%) initially perceived having none or some knowledge of this competence, and a smaller proportion of students (44%) considered themselves having normal or high knowledge. But in the final situation, the results changed and only 10% of the students considered they had none or some knowledge, and now a 90% of students considered themselves to have normal or high knowledge, more than double what they perceived in a beginning.

Finally, on the contextual competence, Project Orientation, Fig. 3 shows great changes in the perception of students about their knowledge. A greater proportion of students perceived having none or some knowledge (67%) of the competence at

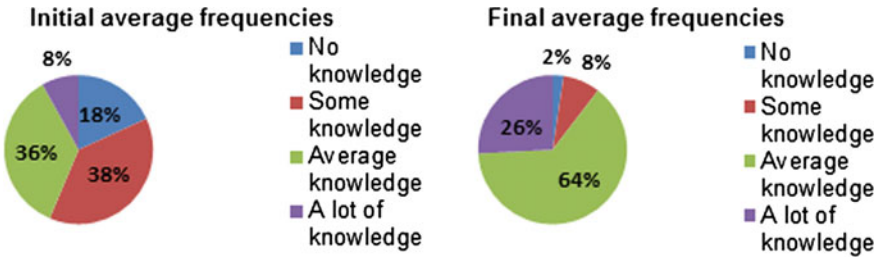

Fig. 2 Historical average frequencies of the competence Conflict and crisis. *Source* Prepared by the authors

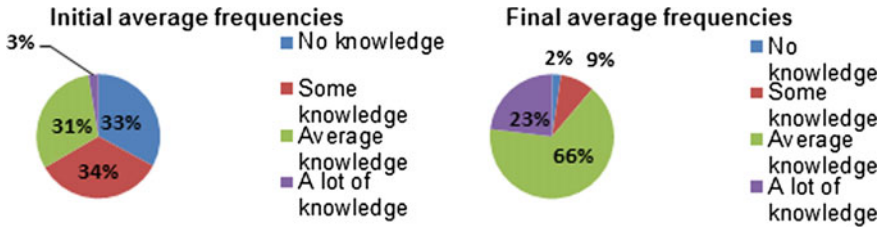

Fig. 3 Historical average frequencies of the competence Projects Orientation. *Source* Prepared by the authors

the beginning, and 34% considered having a normal or a high level of knowledge. At the end of the course the perceptions were reversed, being the proportion of students that perceived having none or some knowledge lowered to only 11%, and the proportion of students with a normal or high level of knowledge increased to 89%, demonstrating a high percentage of improvement.

5.2 *Qualitative Analysis*

As mentioned in the methodology, the technical competences were assessed in all the types of evaluations that were performed in the course, giving as a result, Table 6.

Sixty-one percent (61%) of students improved the Project Management Success competence (1.01). According to the patterns, students improved this competence mainly due to the work performed in the deliverable of the project management plan. This management plan integrates all plans, such as cost, quality, time, etc., for the purpose of assessing these plans, accepting and communicating them to all stakeholders and interested parties, achieving a great control of their project management which leads to success.

Fifty-seven percent (57%) of students improved the Stakeholder's competence (1.02). According to the patterns, students tended to succeed in their final project thanks to the development of this competence in the deliverables of the project charter and Management Plan II. This is because in the articles of incorporation, students had to identify all the stakeholders for their projects and what they needed. Also, in Management Plan II, students developed several sections of their project considering stakeholders, and how they should organize the communication with all of them, their level of interest in the project, the information they should communicate to each one, how to improve their level of interest and communication, etc.

Sixty-seven percent (67%) of students improved the Project Requirements and Objectives competence (1.03). By analyzing the patterns of improvement, the vast majority of students mainly based their improvement on the development of the

Table 6 Location of competencies in the projects course 2014

Competence	Exams				Deliverables						Final project
	E1	E2	E3	E4	Project charter	Scope statement	General Plan I	General Plan II	Management plan	Closing report	
1.01	x	x	x	x					x		x
1.02	x	x	x	x	x			x			x
1.03	x	x	x	x	x	x	x				x
1.06	x	x	x	x				x			x
1.09	x						x				x
1.10	x	x	x	x	x	x					x
1.20	x	x	x	x						x	x

Note: *1.01* Success in project management, *1.02* Stakeholders, *1.03* Requirements and objectives of the project, *1.06* Organization of the project, *1.09* Structures of the project, *1.10* Scope and deliverables, *1.20* Closing

Source Prepared by the authors

project charter and the statement of the scope. This is because in these deliverables, to properly define their project, students had to gather all the requirements that their stakeholders requested, the objectives to achieve and also had to plan how to deal with the project management. In addition to defining their objectives and deliverables, students had to organize themselves and relate to each other, by using a traceability matrix.

Seventy-nine percent (79%) of students improved in the Project Organization competence (1.06). By analyzing the patterns, it is shown that the greatest reason for improvement was due to the development of their Management Plan II. In this plan, students were in charge of organizing their project teams, in addition to produce the organization chart, defining the roles and responsibilities the project would have, if carrying it out, the people to consult in each section of their project, the rules and regulations to follow during the course of the project, the training each person would need, their competencies, the safety aspects to consider, etc. Students had already learned how to organize themselves, because they have had to work in teams in all their university career, but it was in this course where they learned the great importance of good organization, the definition of roles and responsibilities, and the internal regulations to consider and how all this is essential to take into account in real projects they would have to manage in the future.

Sixty percent (60%) of students improved in competence 1.09, Project Structures. This competence was strongly related to competence 1.06, only that in this case, the structures and organizations were focused more on the content of the project and on its cost, time and quality. Students developed this competence in greater depth in Management Plan I, where they had to divide their project into phases, deliverables and work packages using a Work Breakdown Structure (WBS) to organize the content of their project. They also had to structure the activities to optimize their performance, with their respective costs and resources, indicating the duration and sequence of activities to capture everything in a Gantt diagram which allow them to see and control the project's progress.

Sixty-nine percent (69%) of students improved the competence Project Scope and Deliverables (1.10). According to the patterns, the greatest development of this competence was seen in the project charter and in the scope statement. In these documents, students defined and delimited the scope of their projects, the budget they required, restrictions they would have and the assumptions they would take into account. The scope statement was one of the most difficult parts of the project definition. They had to deliver change requests regarding this part many times, because students at the beginning included many aims but then they realized that their scope should be better defined, they had to reduce or delimit some of them to obtain better results.

Regarding the last technical competence, Closure of the Project (1.20), 74% of students showed improvement. Analyzing the patterns, the improvement was due in great part to the development of Closing of the project deliverable, where students did a recount of what was performed in the whole the management of the project, the final statement of their costs, problems, risks, baselines, objectives achieved at the end, the status of their deliverables and a reflection on the lessons learned in the

project, in order to have them documented and be able to share it for similar future projects.

As it was mentioned in the methodology, for the competence Behavior, Conflict and crisis (2.12), observations made by researchers, experiences from monitors and some students were review. The main problems detected are listed as follows:

- Absence at team meetings (justified or unjustified).
- Lateness arriving to meetings.
- Lack of coordination due to different course loads from each student of the group.
- Lack of time due to extracurricular activities and/or work.
- Different ways of working of each member.

The solutions to these situations that the students worked out were: the division of the workload among students that could be loaded a little bit more due to their schedules, organizing it by the workload of the project according to the time availability for each member, meeting days where set such that all or most of the team members could attend, and afterwards informing people that due to force majeure, could not attend.

Regarding the crisis, the most common reasons given were the following:

- Lack of commitment to the project.
- Strong differences of opinion among the team members.
- Some students feel their opinions and contributions are not appreciated by the director and/or the group as a whole.

Students usually appeal to the professor and/or their monitor for advice. It became evident that the optimal way for resolving these crises was by performing a circle of conversation, where each student should be honest about the work realized by each of his teammates, providing constructive criticism if it has been felt that some of their teammates have not made enough effort or were not committed to the project. This type of exercises helped the students to overcome crises by working as a team and being honest. The monitor's guidance is essential in facing crises, because most of the times, students don't know what to do or take wrong decisions. By having these conflicts or crisis situations and overcoming them, students developed this competence to a large extent.

Finally, as it was already mentioned, for the Contextual competence, the progress of this competence was analyzed through the assessment of the written exams. It is considered that the entire group already has implicitly this competence, because by taking this course they are already oriented towards projects. The course explains what projects are and what is involved in working in a project. All the PBL methodology, deliverables, communication with stakeholders, time restrictions, cost and scope, risk management, quality compliance, etc., is aimed at performing a successful project and therefore the optimal development of this competence.

In Fig. 4, the curve starts with 20% of students that showed knowledge of the competence orientation to projects, and a few days before the presentation of their

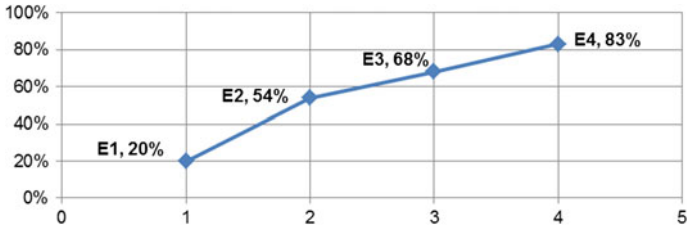

Fig. 4 Progress of the competence Projects Orientation throughout the course. Note: *E1* Exam 1, *E2* Exam 2, *E3* Exam 3, *E4* Exam 4. *Source* Prepared by the authors

final Project, 83% of students approved in this competence, which shows an evident improvement.

6 Conclusions

From the results, it can be seen that students improved, in a greater proportion, the technical competences, and in a lesser proportion, behavioral and contextual competences, in accordance with what IPMA requests to certify a person at knowledge level D.

Another conclusion is that students really perceived improvement in most of their competences. They started in initial situations where their knowledge was null or poor, and at the end of the course, they perceived and showed that their knowledge was normal or very high. This confirms that the course is meeting its objectives of training students towards professional competences which are useful in their working life, and increasing their knowledge. It was also evident that students usually have a somewhat pessimistic assessment of themselves, given that their level of knowledge is greater than what they really perceive.

The main finding was that the methodology of weekly deliverables has helped the students a lot. In each deliverable, students managed and planned their projects, meeting all the necessary requirements to succeed in their projects and in the project management, by managing their scope, costs, time, quality, risks, staff and purchases in an optimal way. In each deliverable, students put to test the competences acquired during their career and during the course. They had to organize themselves, designate tasks, roles, dedicate enough time to their project and stablish priorities. Also, the written exams showed to be a very good tool to test the progress that students experienced when developing their deliverables, giving them cases to analyze and evaluating concepts. All this came to be reflected in excellent grades and comments in the presentations of their projects.

The difficulties found in the projects management were mainly in the management of conflicts, crises and the stress they induced. It is a very common problem, given that students only face project management in this course. In previous

courses, they only perform works or activities but not projects. Despite this, students always reach an optimal solution and manage to overcome these adverse situations, making a great use of their Negotiation and the Management of Conflict and Crisis competences.

Finally, the results showed that 6 of the 9 students that improved the 9 competences were project directors, from a total of 9 project directors that managed 9 course projects in 2014. This shows that the course is useful to prepare good future directors and project managers, developing their competencies optimally to be able to manage real projects in their professional life. This could be the first step for a new study, focusing only on the project directors, to assess the impact of the content that was taught in the course and how it is currently helping them in their working life.

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Retraction Note to: *Guadua angustifolia* as a Structural Material for Greenhouse Design

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The retracted chapter and book have been updated with the changes.

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