Contributions to the implementation of integrated environmental and health and safety management systems in construction companies

DOCTORAL THESIS

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Quan surts per fer el viatge cap a Ítaca,
has de pregar que el camí sigui llarg,
ple d'aventures, ple de coneixences.
Has de pregar que el camí sigui llarg,
que siguin moltes les matinades
que entraràs en un port que els teus ulls ignoraven,
i vagis a ciutats per aprendre dels que saben.

Tingues sempre al cor la idea d'Ítaca.
Has d'arribar-hi, és el teu destí,
però no forcis gens la travessia.
És preferible que duri molts anys,
que siguis vell quan fondegis l'illa,
ric de tot el que hauràs guanyat fent el camí,
sense esperar que et doni més riqueses.

Ítaca t'ha donat el bell viatge,
sense ella no hauries sortit.
I si la trobes pobra, no és que Ítaca
t'hagi enganyat. Savi, com t'hauràs fet,
sabràs el que volen dir les Ítaques.

Konstantin Kavafis

Adaptació de Lluís Llach (1975)
a partir de la traducció de Carles Riba.

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Summary

Most common challenges and obstacles encountered by construction organizations during the implementation process and use of integrated environmental and health and safety management systems are related to the inherent peculiarities of the construction sector. According to several research authors, one of the issues involving a higher level of uncertainty is the integration of planning and control instruments, including elements for identifying and assessing environmental impacts and health and safety risks and implementing subsequent necessary control measures.

This dissertation contributes to the implementation of environmental and health and safety management systems in construction companies by proposing a process-oriented approach and using risk as an integrating factor. The proposed methodology can support the implementation of environmental management systems and occupational health and safety management systems in construction companies or simply help construction organizations to improve their environmental and safety performance and general decision-making.

At a project level, this research proposes a quantitative methodology for dealing with potential adverse environmental impacts and health and safety risks during the pre-construction stages of residential buildings and other similar types. The strength of this methodology lies in the fact that it helps designers to explicitly consider on-site environmental impacts and construction worker safety during the design process. Designers can compare several design alternatives during the design phase and determine the corresponding overall environmental impact level and the overall safety risk level of a construction project without their creative talents being restricted. The methodology is especially worthwhile for those less-experienced designers who lack the skills and knowledge required to recognize environmental aspects and safety hazards in developing optimal designs.

The methodology also serves as an assessment tool for construction companies to measure the environmental and health and safety performance of construction projects and its subsequent construction activities, providing a

consistent basis for comparisons, future labelling and environmental and safety benchmarking among construction projects and construction companies. The suggested methodology also allows construction companies to optimize their on-site performance in the environmental and the health and safety domains during the planning and preparation stages.

Instead of providing a standard set of environmental aspects and health and safety risks, this methodology proposes an exhaustive preliminary analysis with a process-oriented approach, highlighting an integrated approach to the environmental and health and safety domains. In order to objectively assess the environmental impacts' magnitude and the exposure to health and safety risks for a particular construction project, 45 performance indicators have been developed. In order to avoid a typical shortcoming in the assessment methods, these indicators, both direct and indirect, are always based on quantitative data available in the project documents. Current performance levels in construction projects were taken as a baseline for assessment and therefore significance limits for indicators were developed based on a statistical analysis of 55 new-start construction projects. The methodology also includes the assessment of the sensitivity of the location or receptor through 23 qualitative indicators. In these cases, a precise description of the assessment scales has been developed.

The developed methodology not only provides designers with a risk-analysis-based way of evaluating the environmental and safety-related performance of their residential construction designs, but also helps construction companies improve their on-site environmental and safety performance. Once a final design is reached, the methodology highlights the significant remaining environmental impacts and health and safety risks. Improved levels of environmental impacts and safety risks identification will undoubtedly lead to successful on-site environmental and safety management. A range of measures can then be implemented at the construction site to eliminate the remaining impacts and risks or reduce them to an acceptable level. In order to promote the integrated operational control of on-site environmental impacts and health and safety risks, this research proposes an ontology-based approach. Understanding relationships between environmental impacts, health and safety risks, construction processes and work instructions provides an integrated approach to help contractors to manage and control environmental impacts and health and safety risks related to the construction process.

In order to increase the usability of this research, the developed methodology has been implemented in a web-based information and knowledge

management system. This application allows a significant reduction of the time devoted to the assessment of each construction project. At the same time, formalizing and visualizing the developed ontology-based approach offers guidance to contractors on the integrated management of many of the environmental and health and safety incidences at the construction site.

Finally, this dissertation documents the verification and validation of the developed methodology and corresponding web-based implementation tool through four types of validity. Conceptual methodology validation ensures that the theories and assumptions underlying the conceptual methodology are correct and reasonable. Data validation ensures that the data necessary for methodology building, evaluation and testing are adequate and correct. Computerized methodology verification is accomplished by testing the web-based implementation tool, allowing to make sure the system is operating according to the conceptual methodology and without errors. Finally, operational validation ensures that the methodology's output behaviour has sufficient accuracy through the analysis of two different case studies. Case studies also illustrate the practical use of the developed methodology.

The dissertation concludes by outlining the main contributions of this research. Those subjects that exceed this dissertation scope are commented on and proposed as future work.

Keywords: environmental management, health and safety management, integrated management systems, construction companies, environmental impacts, health and safety risks, construction projects, construction processes, ontology, integrated operational control.

Contents

List of Acronyms

BSI	British Standards Institution
CHPtD	Construction Hazards Prevention through Design
EIA	Environmental Impact Assessment
EM	Environmental Management
EMAS	Eco-Management and Audit Scheme
EMS	Environmental Management System
IMS	Integrated Management System
ISO	International Organization for Standardization
MS	Management System
MSS	Management System Standard
OHSM	Occupational Health and Safety Management
OHSMS	Occupational Health and Safety Management System
QM	Quality Management
QMS	Quality Management System

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Chapter 1

Introduction to the thesis

1.1 Introduction

This chapter provides an introduction to this thesis, which is focused on the subject of integrated environmental and health and safety management in construction companies, as a fulfilment for the title of Doctor by the Technical University of Catalonia. It states the problem, outlines the main aims and objectives of the research project and sets out the scope of the work and its limitations and delimitations before describing the remaining structure of this dissertation.

1.2 Problem statement

Quality management (QM) within building and civil engineering has become an established and accepted function over the last 25 years. However, pressure from clients, industry standards and legislation has emphasized the requirements not only for high-quality outputs but also end-products that are delivered using safe and environmentally empathic methods (Griffith and Bhutto, 2008a).

Having recognized the importance of environmental and health and safety implications related to construction activities, environmental management systems (EMS) and occupational health and safety management systems (OHSMSs) have also been introduced in the construction industry. However, these systems have been widely accused of being bureaucratic, arduous, paper driven and of questionable value to construction management (Griffith et al., 2000). In addition to general implementation barriers that may affect all sectors, previous researchers suggest that the inherent peculiarities of the construction industry (generally focused on

individual projects, involving not only an important geographic dispersion and a high temporality but also a high variability in construction techniques and systems) hamper even more the implementation of management systems (MSs) in construction companies (Bhutto et al., 2004; Piñeiro and García, 2007). This is the reason why MSs are frequently applied to isolated parts of a [construction] organization (Karapetrovic, 2002). In a parallel way, the difficulty of operating multiple parallel MSs at the same time (Zeng et al., 2007) and an increased compatibility between the different standards (Jørgensen, et al., 2006) have been proved, emerging the idea of integration. It has been widely argued that integrated management systems (IMSs) reduce wasteful redundancies and possibly generate positive synergy effects (Karapetrovic, 2002).

Understanding that integration is more than combining documentation of various MSs (Pheng and Pong, 2003), many research authors have documented the need for effective ways of integrating currently separate MSs (Labodová, 2004). In this sense, research conducted to date covering the most common obstacles encountered by organizations during the implementation process of an IMS highlights a lack of technical guidance (Zeng et al., 2005; Zutshi, 2005; Zeng, et al., 2007; Salomone, 2008; Zeng et al., 2008). According to empirical studies reported by several authors, one of the issues involving a higher level of uncertainty during the implementation process of an IMS is the integration of the elements corresponding to identification, evaluation and control of environmental impacts and health and safety risks (Pheng and Shiua, 2000; Salomone, 2008; Seiffert, 2008). Other authors also recognise that the sub-system for identifying environmental aspects and health and safety hazards and analysing their impact plays an important role in the integrated environmental and health and safety systems (Labodová, 2004; Seiffert, 2008).

1.3 Aim and objectives

According to what has been stated in subsection 1.2 (Problem statement), the main hypothesis is that IMSs are not as widespread in the construction sector as other industrial sectors because of their inherent peculiarities. The previous subsection proves that the most common obstacles encountered by construction organizations during the implementation of integrated environmental and occupational health and safety management systems relate to a lack of technical guidance.

Consequently, the primary aim of this dissertation is to facilitate the implementation and use of integrated environmental and occupational health and safety management systems in construction companies by establishing the necessary basis and criteria to identify, assess and control environmental impacts and health and safety risks related to the construction process.

The research conducted within this thesis is expected to benefit construction companies and construction projects by overcoming the most common challenges and obstacles related to the implementation of IMSs. The implementation and use of IMSs is seen by the existing literature as a reasonable way to achieve simpler and more focused management systems, better utilization of resources, saving of money and time, more efficient internal and external audits, greater acceptance and understanding among employees, and, enhanced confidence of customer and positive market / community image.

Assuming that integration is more than combining documentation of various systems, this research focuses on the development of a process-oriented methodology using risk as an integrating factor (risk for the environment and risk for life and health of employees and surrounding population). In fact, the theory of hazard identification, risk assessment and control is identical in the environmental and the health and safety domains. That is, the notion of injury or illness equally applies to damage to the environment and the downstream affects on those who live in the environment (Trethewy et al., 2003).

This dissertation is conducted in order to achieve the following aim and objectives:

Aim: To develop a process-oriented methodology to enhance the integration of environmental and health and safety management systems for construction companies focusing on the sub-systems for identifying, assessing and operationally controlling environmental aspects and health and safety hazards using risk as an integrating factor.

Objective 1: To identify and examine challenges and obstacles encountered by construction organizations during the implementation process and use of environmental management systems, occupational health and safety management systems and integrated environmental and health and safety management systems.

Objective 2: To identify and examine shortcomings in the current approaches addressing potential on-site environmental impacts and construction worker safety in both the design and construction planning stages.

Objective 3: To identify environmental aspects and health and safety risks related to the construction process with a process-oriented approach.

Objective 4: To assess the environmental aspects and the health and safety risks at the pre-construction stage.

Objective 5: To develop a guidance tool for effective on-site integrated environmental and health and safety management using an ontology-based approach as a technical solution.

Objective 6: To verify and validate the developed methodology.

1.4 Scope of the research, limitations and delimitations

The scope of this research includes the development of a process-oriented methodology to enhance the integration of environmental and health and safety management systems for construction companies focusing on the sub-system for identifying, assessing and operationally controlling environmental aspects and health and safety hazards. The sub-system for monitoring and measuring, which is focused on demonstrating continual improvement, requires real performance data acquisition and for this reason it is out of the scope of this research.

The developed methodology considers those construction processes which are related to residential buildings, including single-family houses, multi-family dwellings and other similar types. However, this research excludes other types of buildings since construction processes can vary significantly. For the same reason, the methodology refers to new-start construction projects, without including big demolition operations, refurbishment or urbanization work.

The boundary of the developed methodology includes the analysis of the potential on-site environmental impacts and health and safety risks, without taking into account potential impacts or risks that may have occurred during the materials' manufacturing phase or those that could occur later, during the building lifespan. The methodology takes into account the environmental and safety consequences of on-site activities. Therefore, environmental impacts or health and safety risks derived from office tasks are not considered within the methodology.

This research covers the most widespread construction techniques and systems in Spain. The inclusion of other construction techniques and systems would significantly increase the extension of the research. For the same reason, basic facilities are not included in the methodology. In addition, special on-site activities such as works involving asbestos manipulation or works in septic tanks have not been considered either.

Direct risks (those that directly emanate from the construction project) are included within the methodology. However, indirect risks such as the existence of

contaminated soil or groundwater are not necessarily a direct result of the construction project and therefore they have not been considered.

Significance limits for environmental and health and safety indicators have been obtained assuming as a baseline the 'typical' or 'average' performance levels in Spanish construction projects. Therefore, significance limits corresponding to developed indicators might not accurately reflect construction practices widespread in other countries.

Both the overall environmental impact level and the overall safety risk level of a construction project are obtained by a simple aggregation of all the points awarded to each criterion. Assuming that all criteria within the environmental domain are of equal importance and that each criterion within the safety domain also has the same significance, this research proposes a weighting system where all the weighting factors are 1. Although it must be recognized that discerned weighting scores would report more valuable outcomes, weighting systems are still considered to be a highly controversial area. To work out a reasonable weighting system within the framework of the developed methodology would entail a great deal of work and for this reason it is out of the scope of this research.

When developing the methodology within the safety domain, immediate causes of accidents (related to unsafe conditions) have been considered. Although it was expected that contributing causes of accidents, especially those related to manageable factors, could be important when predicting and assessing potential safety risks at the pre-construction stage, no significant correlation between the on-site safety performance and contributing causes of accidents was found during a preliminary study.

1.5 Thesis structure

This thesis documents the research undertaken in fulfilment of the requirement for the title of Doctor by the Technical University of Catalonia. It is structured as follows:

Chapter 1 introduces the research project, provides a background to the research problem, identifies the aim and objectives of the research project and sets outs the scope of the work and its limitations and delimitations before describing the remaining structure of the thesis.

Chapter 2 presents a critical literature review about the existing knowledge on the integration of environmental and occupational health and safety management systems in construction companies. Having outlined the main barriers to IMSs

implementation in construction organizations, this chapter, together with the following one, serves as justification of the research undertaken within this project.

Chapter 3 provides an overview of previous works related to the research domain and highlights how this research project builds on those which have preceded it, demonstrating innovation in the application of knowledge to the integration of environmental and health and safety aspects during the pre-construction stages.

Chapters 4 and 5 detail the work undertaken to meet the research project's aim and objectives. Chapter 4 develops a methodology that provides an effective way of integrating currently separate management systems for environmental and health and safety management in construction companies focusing on the sub-system for identifying and assessing environmental aspects and health and safety hazards using risk as an integrating factor. Chapter 5 focuses on enhancing integrated operational control for on-site environmental and health and safety management using an ontology-based approach as a technical solution.

Chapter 6 documents the verification and the validation process of the developed methodology and corresponding web-based implementation tool. Conceptual methodology validation, data validation, computerized methodology verification and, operational validity are analysed. Two case studies, randomly chosen to operationally validate the developed methodology, also illustrate practical uses of the research undertaken.

Chapter 7 concludes by summarizing the key findings of the research and sets out how the project has contributed to knowledge and practice and presents areas suitable for further research.

Appendices A to E include additional supporting material as evidence of research undertaking.

Figure 1 shows the outline of this dissertation.

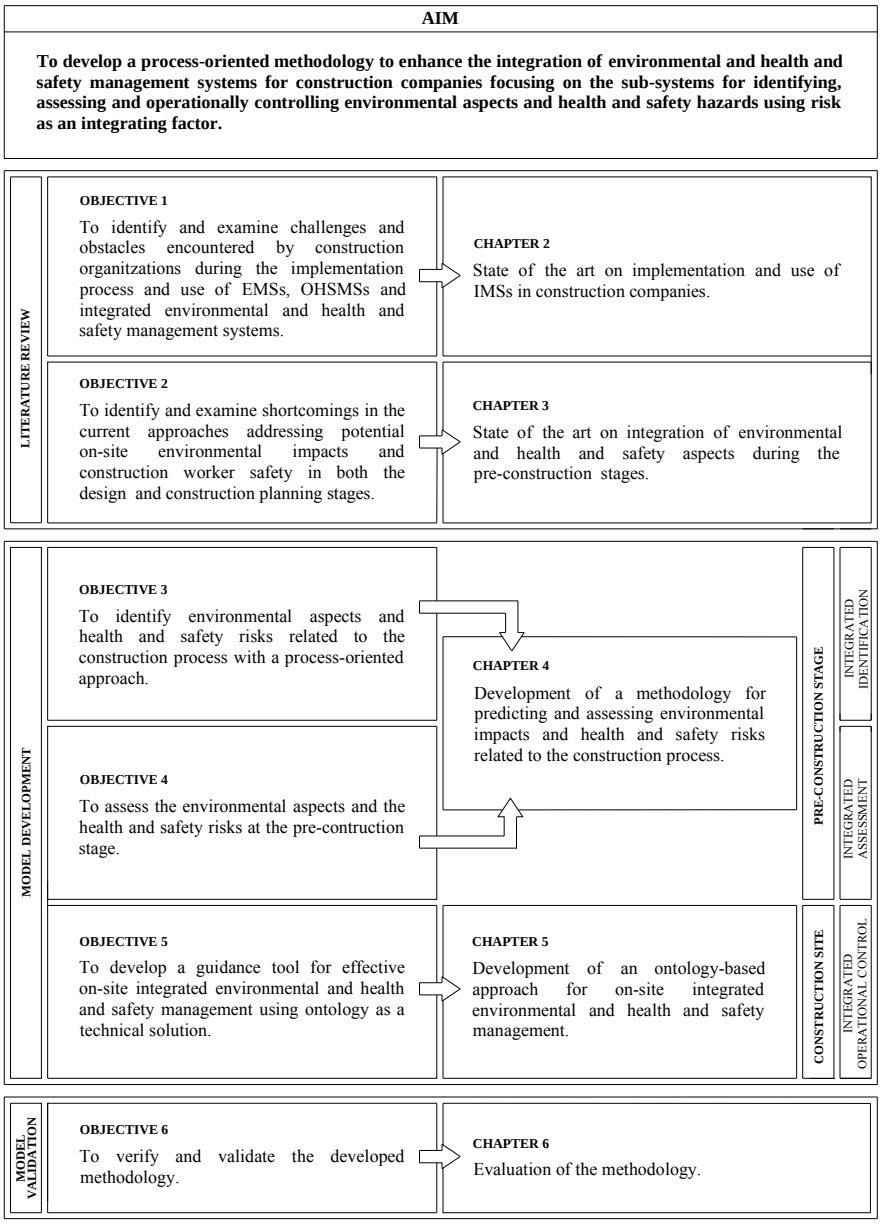

Fig. 1. Thesis outline.

Chapter 2

State of the art on implementation and use of IMSs in construction companies

2.1 Introduction

This chapter imparts the findings of a literature review carried out to gather work and thoughts of academics, experts and practitioners within the subject field. It begins by briefly examining the most widespread and well-recognized management systems (MSs) in construction firms. It then examines the concept of integrated management systems (IMSs) and explores the most common scopes, strategies and degrees achieved in their implementation. Benefits and barriers to IMSs implementation are also discussed. Having outlined the main barriers to IMSs implementation in construction companies, this chapter, together with the following one, serves as a justification of the research undertaken within this project.

2.2 Management systems

Organizations establish formal or documented MSs to provide the necessary framework of command, communications, operational processes and arrangement of resources that enable the organization to achieve its business objectives (Hoyle,

1998; Griffith and Bhutto, 2008a). Construction organizations use MSs to configure their approach to business activities, translating these into operational procedures for application on the construction projects they undertake (Griffith et al., 2000). The most widespread and well-recognized MSs are standards-based and focus on quality, environment and occupational health and safety (Zutshi, 2005; Zeng et al., 2007).

2.2.1 Quality management systems

From an historical point of view, the first broadly explored managerial system was the quality management system (QMS) (Labodová, 2004). According to Wilson (1996), QM can be defined as all activities of the overall management function that determine quality policy, objectives and responsibilities, and implement them by means such as quality planning, quality control, quality assurance and quality improvement within the quality system. The standardized systems for QM can be generally implemented according to several standards. From these, the ISO 9000 approach is the most commonly used system. This model is broadly used internationally (Labodová, 2004).

According to a survey conducted by the International Organization Standardization (2008c), 951,486 quality certificates were issued by the end of December 2007 in more than 150 countries and economies.

2.2.2 Environmental management systems

In parallel with the evolution of quality standards, several norms of environmental management (EM) were developed that had a similar structure to environmental management requirements (Labodová, 2004). Starting with several national norms, the process evolved into the European-wide Eco-Management and Audit Scheme (EMAS). Almost simultaneously with the development of the European EMAS, the ISO 14000 series for environmental management systems (EMSs) was developed as a worldwide certifiable EMS (Labodová, 2004). Environmental management standards integrate business practices and environmental goals that enable an organization to manage its potential impact on the environment (Koehn and Datta, 2003).

Since the introduction of the ISO 14000:1996 standards, 90,659 environmental certificates were issued by the end of December 2007 in more than 150 countries and economies (International Organization for Standardization, 2008c), the majority of which are in the manufacturing industry (Koehn and Datta, 2003). Moreover and according to official data provided by the European Commission, 4,320

organizations or 6,886 sites were certified according to the EMAS up until March 2009.

2.2.3 Occupational health and safety management systems

Both QMS and EMS standards have some requirements, which are related to occupational health and safety management system (OHSMS), but do not sufficiently cover all health and safety problems (Labodová, 2004). Driven by the British Standards Institution (BSI), OHSAS 18001 was first published in 1999. It can be described as a de facto standard and is used as the basis for certification of OHSMSs (Jørgensen et al., 2006). The OHSAS 18001 aims to create and maintain a safe working environment, while protecting and maintaining good health of workers (Zeng et al., 2007; Tsai and Chou, 2009). It is relevant to note that this norm is compatible with ISO 9001 and 14001 management system standards (MSSs) in order to facilitate an integration of the three systems (Suarez-Garcia, 2001; Pheng and Tan, 2005; Zutshi, 2005; Jørgensen et al., 2006; Zeng et al., 2007). Although there is no official or precise data relating to the number of OHSMS certifications worldwide; estimates for 2005 gave a figure of 2,000 sites that had obtained OHSAS 18001 certification (Salomone, 2008). According to Salomone (2008), this is considered to be underestimated.

On the other hand, in 2001, the International Labour Organization (ILO) developed its Guidelines on occupational safety and health management systems (International Labour Office, 2001). The consistency of OHSAS 18000 with ISO 9000 and ISO 14000 families of standards, and the possibility for third-party evaluation and certification has made OHSAS most appealing to organizations.

2.2.4 Implementation and use of management systems in construction companies

QMSs have successfully been implemented by contractors over the last 25 years formerly as BS 5750 and in recent years by ISO 9000:2000 [and ISO 9000:2008] (Griffith and Bhutto, 2008a). The construction industry has the third highest number of ISO 9000-certificates among all industrial sectors at a worldwide level (Zeng et al., 2005). Construction related firms accounted for 7% of the total certified companies in all industrial sectors in 2000 (Chini, 2003). This means that approximately 28,600 construction related companies had a quality certificate.

Nowadays, there is a growing emphasis on the implementation of EMS meeting BS EN ISO 14001:2004 (Griffith and Bhutto, 2008a) in contractors' companies. The ISO 14001 certification in construction companies is relatively low compared to ISO

9001 certification in the construction industry (Zeng et al., 2005), with 9,095 certificates in 2006 (Turk, 2009). According to official data provided by the European Commission by February 2009, 216 construction organisations had adopted and implemented an EMAS.

Various indicators point out the fact that a dominant aspect of the implementation and up-keep of an EMS is associated with the planning stage, especially relating to the subsystem/requisite for identifying and assessing environmental aspects and impacts, mostly due to the complexity of the adopted methodologies (Seiffert, 2008). According to Põder (2006), experience obtained from numerous companies has demonstrated that limited transparency and reproducibility of the assessment process is a common shortcoming. Despite rather complicated assessment schemes that are sometimes used, the evaluation procedures have been largely based on subjective judgements because of ill-defined and inadequate assessment criteria (Seiffert, 2008).

Although there is no official or precise data relating to the number of OHSMS certifications worldwide; it is often stated that most contractors are not certified to comply with BSI-OHSAS 18001 (Griffith and Bhutto, 2008a). Within the scope of the construction companies' certification, and according to Zeng et al. (2008) construction firms with an OHSAS certification were 96 (4.5%) in China.

These low certification rates in the construction sector are a consequence of the uncertainty caused by the application of the traditional standards-based management systems, especially at the project level (Griffith and Bhutto, 2008a). This uncertainty is undoubtedly linked to some peculiarities of the construction sector. Contrary to ordinary manufacturing industries, the place of production in the construction sector must necessarily be the place where the product is going to be used (Hochstadt, 2004). Moreover, the construction industry often works on unique products, which may include a large variety of construction techniques and systems (Casals and Etxebarria, 2000). This high variability, the geographic dispersion of production places and the inherent temporality make the implementation of MSs in construction difficult (Piñeiro and García, 2007; Bhutto et al., 2004).

A report on contractor's experiences of traditional standards-based MSs application performed by Griffith and Bhutto (2008a) states that staff often regard systems as a burden and a hindrance to getting their job done. Furthermore, site staff do not fully understand MSs as real and holistically beneficial to both the project and company and they are then lost to a simplistic compliance and checklist culture (Griffith and Bhutto, 2008a).

2.3 Integrated management systems

Until now, normalized systems for QM, EM and OHSM have been developed (Labodová, 2004). Although ISO 9001, ISO 14001 and OHSAS 18001 standards share similar management techniques and principles (Zeng et al., 2007), these are frequently operated as independent systems (British Standards Institution, 2006). In this sense, Griffith and Bhutto (2008a) report that current MSs structure in contractors' companies tends to be vertical and separate for each system. However, research has demonstrated that implementing and operating these standards in parallel demands many duplicate management tasks (Labodová, 2004; Zeng et al., 2007). Hence, IMSs have drawn the attention of both academics and practitioners (Zeng et al., 2007).

Certifiable standards have been designed purposely with a very close formal structure, allowing integration of particular systems requirements into a general and unified IMS (Labodová, 2004). The following table illustrates this compatibility by presenting the correspondence between the different standards.

	OHSAS 18001:2007	**ISO 14001:2004**	**ISO 9001:2008**
0 Introduction	-	-	0, 0.1, 0.2, 0.3, 0.4
1 Scope	1	1	1, 1.1, 1.2
2 Reference publications	2	2	2
3 Definitions	3	3	3
4 Management system elements / requirements	4	4	4
4.1 General requirements	4.1	4.1	4.1, 5.5, 5.5.1
4.2 Management system policy	4.2	4.2	5.1, 5.3, 8.5.1
4.3 Planning	4.3	4.3	5.4
4.3.1 Identification and evaluation of aspects, impacts and risks	4.3.1	4.3.1	5.2, 7.2.1, 7.2.2
4.3.2 Legal and other requirements	4.3.2	4.3.2	5.2, 7.2.1
4.3.3. Objectives	4.3.3	4.3.3	5.4.1, 5.4.2, 8.5.1
4.4 Implementation and operation	4.4	4.4	7
4.4.1 Structure and responsibility	4.4.1	4.1, 4.4.1	5.1, 5.5.1, 5.5.2,

	OHSAS 18001:2007	ISO 14001:2004	ISO 9001:2008
			6.1, 6.3
4.4.2 Training, awareness and competence	4.4.2	4.4.2	6.2.1, 6.2.2
4.4.3 Consultation and communication	4.4.3	4.4.3	5.5.3, 7.2.3
4.4.4 Documentation	4.4.4	4.4.4	4.2.1
4.4.5. Document and data control	4.4.5	4.4.5	4.2.3
4.4.6 Operational control	4.4.6	4.4.6	7.1, 7.2, 7.2.1, 7.2.2, 7.3.1, 7.3.2, 7.3.3, 7.3.4, 7.3.5, 7.3.6, 7.3.7, 7.4.1, 7.4.2, 7.4.3, 7.5, 7.5.1, 7.5.2, 7.5.5
4.4.7 Emergency preparedness and response	4.4.7	4.4.7	8.3
4.5 Checking and corrective action	4.5	4.5	8
4.5.1 Performance measurement and monitoring	4.5.1	4.5.1	7.6, 8.1, 8.2.3, 8.2.4, 8.4
4.5.2 Evaluation of legal compliance	4.5.2	4.5.2	8.2.3, 8.2.4
4.5.3 Accidents, incidents, non-conformances and corrective and preventive action	4.5.3	-	-
4.5.3.1 Accident investigation	4.5.3.1	-	-
4.5.3.2 Non-conformance and corrective and preventive action	4.5.3.2	4.5.3	8.3, 8.4, 8.5.2, 8.5.3
4.5.4 Control of records	4.5.4	4.5.4	4.2.4
4.5.5 Internal audit	4.5.5	4.5.5	8.2.2
4.6 Management review	4.6	4.6	5.1, 5.6, 5.6.1, 5.6.2, 5.6.3, 8.5.1

Table 1. Correspondence between OHSAS 18001:2007, ISO 14001:2004 and, ISO 9001:2008.
Source: Adapted from OHSAS 18001:2007 and ISO 9001:2008.

However, the alignment approach, defined by Jørgensen et al. (2006) as a parallelisation of the systems using the similarities of the standards to structure the system, should not be mistaken for the integration approach. The integration approach goes one step further (Jørgensen et al., 2006) and involves full integration in all relevant processes.

Integration is defined differently by researchers (Jørgensen et al., 2006; Zeng et al., 2007). Garvin (1991) refers to integration as the degree of alignment or harmony in an organization. In Beckmerhagen et al. (2003), integration is defined as 'a process of putting together different function-specific MSs into a single and more effective IMS'. MacGregor Associates (1996) see integration as a single top-level management 'core' standard with optional modular supporting standards covering specific requirements. In Karapetrovic and Willborn (1998) and Karapetrovic (2003), an IMS is characterized by a complete loss of the unique identities of these subsystems and can be defined as a 'set of interconnected processes that share a pool of human, information, material, infrastructure, and financial resources in order to achieve a composite of goals related to the satisfaction of a variety of stakeholders'. For Pojasek (2006), 'a genuinely integrated system is one that combines MSs using an employee focus, a process view, and a system approach, that makes it possible to put all relevant management standard practices into a single system'. Combining these definitions, Bernardo et al. (2009) summarize integration as 'a process of linking different standardized MSs into a unique MS with common resources aiming to improve the stakeholders' satisfaction'.

Although there is no formalized IMS which can be [internationally] certified (Labodová, 2004), in 2006, the BSI published the Publicly Available Specification of common MS requirements as a framework for integration (British Standards Institution, 2006). The aim of this specification is to help organizations achieve benefits from integrating the common requirements of all MS standards and specifications and managing these requirements effectively. At Spanish level, AENOR also launched the 'Integrated Management Systems Certification'. However, this certification can only be used for organizations with an IMS for quality and environment.

2.3.1 Integration scopes

A literature review leads to the conclusion that a vast majority of organizations that comply with multiple MSs have integrated the subsystems these standards represent at any level. In this sense, the empirical analysis performed by Karapetrovic and Casadesus (2009) among companies from different sectors indicates that 85% of the respondents in the survey claimed cross-functional integration, while only the remaining 15% had not integrated their standardized MSs. Other significant

conclusions can be drawn from the study carried out by Karapetrovic and Casadesus (2009). Most of the organizations surveyed (63%) had integrated quality, environmental and other sector specific subsystems, while only 15% had put the OHSMS together with the other subsystems: 12% of the organizations integrated the EMS, QMS and the OHSMS while a further 2% integrated these MSs with other sector specific subsystems. Only 1% of the organizations integrated EMS and OHSMS without QMS.

However, there is no reliable data concerning the implementation and use of IMSs in construction companies. Only a few statistical studies have been made in order to perceive the contractor's opinion on IMSs in construction. Zeng et al. (2005) analysed the Chinese construction companies' view on the advisability in integrating ISO 9001 and ISO 14001 standards. The findings reveal that a majority of firms (59%) support an integration of these standards mainly because of their 'similarity' and 'compatibility'. Pheng and Tan (2005) also performed a similar study on the integration of these management standards, highlighting possibilities, difficulties, benefits and costs.

QMS and EMS have been integrated with some success by construction companies, yet OHSMS is seen as more inflexible and generally based on compliance with health and safety legislation rather than system standards (Griffith and Bhutto, 2008b). In this sense, Zeng et al. (2008) reported a low status of OHSAS implementation in the Chinese construction industry and suggested to integrate it with ISO 9001 QMS. Pheng and Shiua (2000) confirmed that there are similarities between an OHSMS and a QMS and demonstrated that it is technically possible and desirable to integrate these MSs. Zeng et al. (2008) also stated that despite having similar requirements, the implementation of OHSMS and QMS is still hard to be combined and administered. In similar research, Pheng and Pong (2003) obtained interesting findings on the possibility/difficulty and benefits/costs of integrating OHSAS 18001 and ISO 9001.

Current approaches to IMSs focus ostensibly on merging systems documentation for specific management function with and existing QMS (Griffith and Bhutto, 2008a). Therefore, there is a paucity of studies on IMSs based ISO 14000 or EMAS and OHSAS 18000 standards in the construction industry.

In some other studies focusing on the construction sector, the scope of integration includes the three most popular standardized management subsystems (quality, safety and environment). Pheng and Kwang (2005) examined the costs and benefits that can be achieved by integrating the three systems into a common MS for the construction industry. On one hand, Koehn and Datta (2003) developed a portion of a quality, environmental and safety management system for a medium to large size

construction company. Not only for being excessively generic, but also due to its inherent subjectivity, the effectiveness of this method is hampered. On the other hand, Shen and Walker (2001) illustrated how to integrate OHSMS, EMS and QM with constructability principles when construction planning.

Griffith and Bhutto (2008a) highlighted an early-stage cultural resistance to IMS implementation on [construction] projects. In order to overcome this barrier, some authors have suggested risk assessment being a central feature of IMS (Labodová, 2004; Griffith and Bhutto, 2008a). According to Labodová (2004), risk analysis is a proper base for a complex MSs and it can be used as an integrating factor: risk for the environment and risk for life and health of employees and surrounding population.

2.3.2 Integration strategies

A part from the particular MSs the organization intends to integrate, strategies include the implementation sequence of these MSs. Researchers have developed different approaches for integrating MSs.

The first integration strategy found during the literature review is the combination of MSs through structural similarities (Karapetrovic, 2002; Pheng and Tan, 2005; Zutshi, 2005; Jørgensen, et al., 2006; Zeng et al. 2008). Obviously, increased compatibility with cross-references between parallel systems is the first step towards IMSs (Jørgensen, et al., 2006). This strategy should include not only documentation integration but also align core processes, objectives and resources (Karapetrovic, 2002; Wilkinson and Dale, 2002). As stated above, the most extended integration strategy includes the integration of OHSMS and/or EMS into a QMS (Douglas and Glen, 2000; Pheng and Shiua, 2000; Shen and Walker, 2001; Karapetrovic, 2002; Wilkinson and Dale, 2002; Griffith and Bhutto, 2008b; Salomone, 2008; Bernardo et al., 2009). QMS is frequently proposed as the host system because it has been highly widespread, especially the ISO 9001 standard.

To successfully integrate QMS, EMS and OHSMS, previous authors also suggest integrating all the systems existing within the organization leading to a complete, true IMS (Labodová, 2004; Zutshi, 2005; Jørgensen, et al., 2006). In this sense, some previous researchers addressed the concepts of ‘a system of systems’ (Karapetrovic and Willborn, 1998) and an ‘all-in-one system’ (Karapetrovic, 2002). According to them, the integration of two systems means linking them in a way that results in a loss of independence of one or both (Karapetrovic and Willborn, 1998). In this sense, the literature proposes the development and implementation of an IMS, integrated from the very beginning, based on an established risk assessment methodology (Labodová, 2004).

2.3.3 Integration degrees

Some elements such as structure, size and economic sector may play decisive role in influencing whether an organization decides to integrate systems and the breadth or depth of integration (Jørgensen et al. 2006; Salomone, 2008).

For example, in the construction sector and according to Hoyle (1998), systems are frequently applied to isolated parts of [a construction] organization rather than the whole and therefore the efficacy of this has been questioned. Applications of this nature are seen as inefficient, bureaucratic, divisive and, cost-ineffective (Griffith and Bhutto, 2008a).

In relation to the integration depth, Salomone (2008) states that almost all companies with totally or partially IMSs take steps to activate unified processes for the control and management of documentation for the systems. This clearly indicates that the main result the companies wish to achieve with an IMS is to reduce documentation and the connected control procedures for the systems. However, the statistical study conducted by Salomone (2008) also reveals that other implementation activities rank lower percentages, such as 'analysis of environmental aspects and health and safety risks' (66%) and 'operational control' (68%). In this sense and based on a survey of 96 construction firms, Pheng and Shiua (2000) found that, in general, most interviewees indicated that it was relatively easy to integrate most of the elements except 'planning for hazard identification, risk assessment and risk control'. Specifically, 82% of the respondents did not find it easy to integrate the elements for identifying hazards, assessing risks and implementing necessary control measures or they did not indicate if it would be possible (Pheng and Shiua, 2000).

2.3.4 Benefits from integrated management systems implementation

A literature review highlights the potential benefits of integrating their different MSs into a single system (Zutshi, 2005). The most cited tangible and intangible benefits of integration identified by the existing literature are detailed next:

- Simpler and more focused MSs in the organization.
  Simpler systems are easier to understand and control (Pheng and Pong, 2003; Pheng and Tan, 2005; Zutshi, 2005; Jørgensen et al., 2006; Zeng et al., 2008).

- Better utilization of resources.
  Reduction in duplication of policies, procedures and records and therefore reduction in volume of paper (Pheng and Pong, 2003; Zutshi, 2005; Zeng, et al., 2005; Pheng and Kwang, 2005; Pheng and Tan, 2005; Zeng, et al., 2008).

- Cost saving.
  More efficient re-engineering due to improvement in data and personnel management, IMS training program for employees, less certification, staff and consulting costs (Pheng and Pong, 2003; Pheng and Kwang, 2005; Zutshi, 2005; Zeng et al., 2007; Salomone, 2008; Zeng et al., 2008).

- More efficient use of internal audits to prepare for third party assessment and reduction of external audits.
  Joint audit systems resulting in an overall system improvement (Pheng and Pong, 2003; Pheng and Kwang, 2005; Pheng and Tan, 2005; Zutshi, 2005; Zeng et al., 2007; Salomone, 2008; Zeng et al., 2008).

- Greater acceptance and understanding among the employees.
  The three objectives (customer satisfaction, environmental compliance and, employee safety) are considered for all operations resulting in higher staff motivation and lower inter-functional conflicts (Pheng and Pong, 2003; Pheng and Tan, 2005; Zutshi, 2005).

- Time saving.
  Adopting different systems as a common objective of continuous improvement avoids confusions resulting from conflicting messages (Pheng and Kwang, 2005; Zutshi, 2005; Salomone, 2008; Zeng et al., 2008).

- Enhanced confidence of customers and positive market/community image. (Pheng and Pong, 2003; Pheng and Kwang, 2005; Pheng and Tan, 2005; Zutshi, 2005).

2.3.5 Barriers to integrated management systems implementation

According to the literature review, some of the most common obstacles encountered by organizations during the implementation process of an IMS include:

- Lack of technical guidance and support from certification bodies.
  Differences between quality, environmental and occupational health and safety management systems create difficulties for firms when implementing an IMS. Although some prominent certification bodies have developed IMS packages (Griffith, 2000), most of them have no reference to IMSs or they do not simultaneously cover quality, environment and safety. In Spain, AENOR launched the 'Integrated Management Systems Certification' but only covering quality and environment. In addition, there is a lack of sector-specific guidance and material tailored to suit different types and sizes of firms (Zeng et al., 2005; Zeng et al., 2007; Salomone, 2008; Zeng et al., 2008).

- Lack of qualified personnel to cover all system requirements.
  Consultants are generally used by a number of organizations to overcome this barrier, requiring high fees over an extended period of time and not assisting the organization in maintaining the implemented system (Pheng and Pong, 2003; Pheng and Kwang, 2005; Zutshi, 2005; Zeng et al., 2007; Salomone, 2008; Zeng et al., 2008).

- Time delays in integration.
  To initially understand and implement an IMS could take more time than anticipated (Pheng and Kwang, 2005; Zutshi, 2005).

- People's attitude.
  Implementing new systems or even updating existing procedures can involve substantial changes that may cause some resistance. Traditionally, organizations have separate, competing staff groups to handle the different MSs (Pheng and Kwang, 2005; Zeng et al., 2005; Zutshi, 2005; Zeng et al., 2007; Zeng, et al., 2008).

- Risk of not assigning the right level of importance to each variable: quality, environment, safety.
  This may result in either costs exceeding benefits or not obtaining the full benefits (Zutshi, 2005; Jørgensen et al. 2006; Salomone, 2008).

2.4 Summary

This chapter has provided an overview of the relevant research that has been conducted within the area of IMSs in construction. It has identified and examined challenges and obstacles encountered by construction organizations during the implementation process and use of environmental management systems,

occupational health and safety management systems and integrated environmental and health and safety management systems. This chapter, together with the following one, serves as justification of the research undertaken within this dissertation.

The literature review demonstrated that construction companies have implemented QMS like in other industrial sectors. However, and in spite of their importance, EMS and especially OHSMS have been less widespread within companies from the construction sector. In addition to general implementation barriers that may affect all sectors, previous authors suggest that the inherent peculiarities of the construction industry (not only a high variability in construction techniques and systems and the geographic dispersion of production places but also the inherent temporality of the construction projects) hamper the implementation of MSs in contractor companies (Bhutto et al., 2004; Piñeiro and García, 2007).

The literature review found that current MSs structure in contractors' companies tends to be vertical and separate for each system (Griffith and Bhutto, 2008a). However, research have demonstrated that implementing and operating these standards in parallel demands many duplicate management tasks (Labodová, 2004; Zeng et al., 2007). IMSs have been strongly advocated by many researchers to overcome these problems. Moreover, and according to a comparison made between elements of ISO 14001:2004 and OHSAS 18001:2007 (Table 1), integration is feasible as there are common elements which serve similar purposes in both standards.

Research conducted to date shows that there is a significant lack of case studies on the implementation and use of IMSs in construction companies. Moreover, current approaches to IMSs focus ostensibly on the integration of QMSs and EMSs or OHSMSs. Therefore, little consideration has been given to the integration of OHSAS 18000 and ISO 14000 or EMAS in the construction sector.

Different strategies of integration have also been discussed in the literature, from those which only include the combination of MSs through structural similarities (mainly alignment of documentation, processes, objectives and/or resources) to those called 'a system of systems' or 'all-in-one' system. It was generally found that the companies integrate their MSs at the alignment level. This means that the companies focus on integrating common elements in the standards by combining documentation, although integrating these MSs into one complex MS for each company is more desirable.

Existing literature also highlights that some elements such as structure, size and economic sector may play a decisive role in influencing the breadth or depth of integration of the MSs of an organization (Jørgensen et al., 2006; Salomone, 2008).

In the construction sector and due to its peculiarities, systems are frequently applied to isolated parts of a construction organization rather than the whole (Hoyle, 1998; Griffith and Bhutto, 2008a).

The literature review revealed a number of quantifiable and un-quantifiable benefits experienced by the companies from operating one integrated system such as simpler and more focused MSs in the organization, better utilization of resources, saving of money, more efficient use of internal audits and reduction of external audits, greater acceptance and understanding among employees, saving of time and enhanced confidence of customers and positive market/community image. However, for the benefits to happen, it is essential that organizations be aware of the challenges and obstacles accompanied by integration of systems/standards. Most common obstacles encountered by organizations during the implementation process of an IMS relate to a lack of understanding of how best to integrate the different MSs (Griffith and Bhutto, 2008a). Lack of qualified personnel to cover all system requirements and lack of technical guidance are commonly cited barriers in the literature. Previous research states that the less common area of integration in the companies is the integration of planning and control instruments. In a survey conducted by Pheng and Shiua (2000), more than 80% of the respondents did not find easy the integration of the elements for identifying and assessing risks and implementing necessary control measures or they did not indicate if it would be possible. Empirical results from Salomone (2008) also corroborate these findings. Applications of this nature are seen in the literature as inefficient, bureaucratic, divisive and cost-ineffective (Griffith and Bhutto, 2008a).

2.5 Implication of the results

This dissertation will address the shortcomings outlined above by focusing on the development of a methodology to support the implementation of integrated environmental and health and safety management systems in construction companies.

Assuming that integration is more than combining documentation of various systems and as suggested by Labodová (2004), risk will be used as an integrating factor: risk for the environment and risk for life and health of employees and surrounding population (Labodová, 2004; Zeng et al., 2007) and according to the point of view of Mackau (2003), it will be addressed with a process-oriented approach. In fact, the theory of hazard identification, risk assessment and control is identical in the environmental and the health and safety domains. That is, the notion of injury or illness equally applies to damage to the environment and the downstream effects on those who live in the environment (Trethewy et al., 2003).

The developed methodology will provide an effective way of integrating currently separate MSs for environmental and health and safety management in construction companies. It will contribute to reduce and if possible eliminate as many obstacles as possible before the actual implementation process of an IMS, mainly those related to a lack of understanding of how best to integrate the different MSs, especially during planning for risk identification, assessment and control in construction companies and construction projects. The systematic identification, assessment and control of environmental impacts and health and safety risks will also contribute to reduce the need for qualified personnel and it will also reduce time delays during the implementation of IMSs. By overcoming the aforementioned barriers, the methodology proposed in this dissertation will represent one way of enhancing the implementation process of integrated environmental and safety management systems in construction companies and construction projects.

One way in which benefits of EMS and OHSMS integration can occur is through better coordination of the design and construction phases to allow an integrated approach to influence design details, particularly with reference to its consequences on the environmental and the health and safety domains (Shen and Walker, 2001). For this reason, the developed methodology will identify and highlight important potential environmental impacts or health and safety risks involved in construction works prior to the construction stage. The early identification of these environmental impacts or health and safety risks will enable designers to start a re-design process; otherwise the construction team will be able to react and adapt quickly in order to prevent potential harmful consequences. Thus, instead of considering EMS and OHSMS as an end in itself, notions of systems compliance can be immersed in the natural progression of the construction project.

Chapter 3

State of the art on integration of environmental and health and safety aspects during the pre-construction stages

3.1 Introduction

This chapter first provides an introduction to the environmental and health and safety performance of construction sites. It then provides an overview of relevant literature in relation to the integration of environmental and health and safety aspects during the pre-construction stages, summarizing experiences addressing potential on-site environmental impacts and construction workers' safety in both the design and construction planning stages. Finally, existing shortcomings in the current approaches are identified and examined.

Having established the research already conducted on this subject, this chapter, together with the previous one, highlights how this research project builds on those which have preceded it, demonstrating innovation in the application of knowledge to the integration of environmental and health and safety aspects during the pre-construction stages.

3.2 Overview of on-site environmental and health and safety performance

Construction has been accused of causing environmental problems ranging from excessive consumption of global resources both in terms of construction and building operation to the pollution of the surrounding environment (Ding, 2008). However, most prior construction research attention has been focused on the evaluation of the environmental performance during building operation (Cole, 2000). According to Ding (2008), the interaction between building construction and the environment is still largely unknown. The limited attention given to the on-site construction impact is a consequence of the perceived relatively lower significance of construction impact compared with the lifecycle impact associated with building design and management (Cole, 2000). However, and because the environmental impacts of construction activities have never been adequately quantified, the assumption that the effects of construction are negligible in comparison with the other building phases is supposition (Sharrard et al., 2007). The inherent temporality associated with the on-site construction also contributes to a scant perception of their impact (Cole, 2000). Generally speaking, a non-existing EM in the construction process is not noticed during the life span of the building.

Even building environmental assessment methods, which are based on the concept of Life Cycle Assessment, have been basically focused on the evaluation of the environmental performance during building operation (Cole, 2000). According to Cole (2000), when some of the environmental issues associated with the actual construction and demolition processes are included in environmental assessment methods, their coverage is neither consistent nor comprehensive. In this sense, Bunz et al. (2006) compared and contrasted 10 building environmental assessment methods, namely LEED - Leadership in Energy and Environmental Design (United States), ASHRAE GreenGuide (United States), C-2000 Integrated Design Process (Canada), Commercial Building Incentive Program (Canada), GBTool Green Building Challenge (Canada), BREEAM – Building Research Establishment Environmental Assessment Method (United Kingdom), GreenCalc (The Netherlands), Guideline for Sustainable Building (Germany), CASBEE – Comprehensive Assessment System for Building Environmental Efficiency (Japan), and Hong Kong Building Environmental Assessment Method - HK-BEAM (Hong Kong) in each of the following life cycle areas: programming phase, design phase, building construction, building operation and building demolition.

According to Bunz et al. (2006), and focusing on the building construction phase, the GreenCalc and CASBEE programs do not provide recommendations during the construction phase of the life cycle whereas the other building environmental

assessment methods only include waste management, transportation of building materials, and impact of construction activities on the work site and surroundings (Table 2).

	LEED	ASHRAE GreenGuide	IDP and CBIP	GBTool	BREEAM	GreenCalc	Guideline for Sustainable Building	CASBEE	HK-BEAM
Waste management	X	X	X	X	X		X		X
Transportation of building materials	X						X		
Construction impact on site and surroundings	X	X	X	X	X		X		X

Table 2. Comparison of the coverage of several building environmental assessment methods during the construction phase. Source: adapted from Bunz et al. (2006).

In fact, construction impacts are often assessed only by the presence or absence of environmental protocols (Cole, 2000). Actually, the establishment of environmental procedures during the on-site construction phase should be done after the application of whatever environmental assessment methodology. Indeed, only once the significance of a certain environmental aspect has been assessed, resulting environmental protocols should be applied (Cole, 2000).

Construction activity is inherently site-based and this makes the task of documenting environmental impacts comprehensively somewhat difficult to achieve in practice. However, some existing literature examines the physical impacts arising from construction (Glass and Simmonds, 2007). Uher (1999) stated that on-site construction activities usually result in air pollution, water pollution, resource consumption, traffic problems and the generation of construction waste. According to Chen et al. (2000), sources of construction-related pollution and hazards can be

divided into seven major types: dust, harmful gases, noises, solid and liquid wastes, fallen objects, subsidence and others. Chen et al. (2005) considered eight categories of construction-related environmental impacts: soil and ground contamination, surface and underground water, construction and demolition waste, noise and vibration, dust, hazardous emissions and odours, impacts on wildlife and natural features, and archaeology impacts. According to Cole (2000), the environmental impacts of the construction process fall into the categories of resource use, ecological loadings and human health issues. March (1992) observed the construction industry's environmental impacts under the categories of ecology, landscape, traffic, water, energy, timber consumption, noise, dust, sewage, and health and safety hazards. Shen and Tam (2002) classified the construction-related environmental impacts as the extraction of environmental resources such as fossil fuels and minerals, the extension of consumption of generic resources (land, water, air, and energy), the production of waste that requires the consumption of land for disposal, and the pollution of the living environment with noise, odours, dust, vibrations, chemical and particulate emissions, and solid and sanitary waste. Sharrard et al. (2007) focused their research on the energy implications of the construction process, which had been proved to be 2.6-3.0% of the US's entire energy consumption. According to Cardoso (2005), the typical negative impacts of construction activities include waste production, mud, dust, soil and water contamination and damage to public drainage systems, destruction of plants, visual impact, noise, traffic increase and parking-space shortage, and damage to public space. Research carried out by Glass and Symonds (2007) revealed that construction projects may experience different challenges due to differences in site, locality, parties involved and tolerance levels that make it difficult to predict and address environmental impacts.

Beside causing environmental problems, the construction industry also kills people on unsafe sites (Glass et al., 2008). In this sense, it must not be forgotten that the construction industry is statistically one of the most hazardous industries in many countries (Carter and Smith, 2006; Wang et al., 2006; Camino et al., 2008). For example, in Spain, approximately 30% of fatal accidents in all industries between 2000 and 2006 occurred in the construction industry, killing approximately 350 employees per year (Spain, 2006). Beside causing human tragedy, construction accidents also delay project progress, increase costs and damage the reputation of the contractors (Wang et al., 2006).

According to data provided by Camino et al. (2008) for Spain, the higher number of construction industry injuries are a consequence of overexertion (20.9%), followed by blows from objects and tools (20.5%) and falls from different levels (10.7%). However, the fall from a height is the type of accident with the most severe consequences (41.8%), followed by blows from objects and tools (8.6%).

Nevertheless Camino et al. (2008) also emphasized electric shocks and vehicular accidents because of their special severity.

Apart from identifying root causes of injuries and their prevalence in construction accidents, some authors have identified factors that influence safety performance. In this sense, Camino et al. (2008) demonstrated that the likelihood that an accident will have severe consequences increases when it involves vehicles, scaffolding, structures, or ladders.

Management strategies associated with site safety have also been analysed in the literature. According to Fang et al. (2004), five factors correlate closely with on-site safety management performance: (i) intensity of a foreman's involvement in routine safety management on the site, (ii) overall intensity of management methods that urge workers to be responsible for their personal safety, (iii) intensity of safety supervision given to a crew, which include hazard notices, safety regulations and safety penalties, (iv) project manager's involvement in project safety management and (v) intensity of training and education methods on construction sites (Fang et al., 2004).

The literature recognises some barriers working against the implementation of recommendations aimed at improving on-site working conditions such as the range of stakeholders subjected to workplace conditions largely outside their control and the larger number of small and medium sized companies involved in construction, having limited resources in terms of time, money and in-house expertise in safety and health matters (Molen et al., 2005).

The existing literature has also examined the usefulness of various safety performance measures and it has also addressed how to estimate the cost of accidents and injuries (Wang et al., 2006). Designing strategies for improving safety performance using a behavioural approach has also been extensively discussed within the existing literature (Wang et al., 2006; Carter and Smith, 2006).

3.3 Integrating aspects of environmental management in the pre-construction stages

3.3.1 Addressing potential on-site environmental impacts in the design stage

Unlike in the health and safety domain, in general, building designers are not legally required to consider the potential on-site environmental impact in their designs.

The Council Directive 97/11/EC of 3 March 1997 amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment (known as the Environmental Impact Assessment or EIA Directive) only applies to the assessment of the environmental effects of those public and private projects which are likely to have significant effects on the environment. EIA procedure ensures that the environmental consequences of projects are identified, assessed and minimised before authorisation is given.

The Spanish EIA system (Legislative Royal Decree 1/2008 of 11 January 2008 passing the consolidated text of the Law on the Environmental Impact of Projects) has no thresholds for residential developments, so they will only require an EIA when they are placed on natural reserves or in non-urban areas in case of large developments (over 100 ha). However, thresholds are used in other countries to decide whether or not a residential development proposal should be subjected to EIA:

Country	**Residential developments**
Germany	> 10 ha
Holland	> 2,000 dwellings
Portugal	> 500 dwellings
Spain	n.t.
Bulgaria	n.t.
Switzerland	n.t.
Latvia	n.r.
Tunisia	> 20 ha
Niger	n.t.
Chile	> 80 dwellings
Mexico	n.t.
Vietnam	n.t.

n.t.: no thresholds specified, n.r.: non-regulated activity.

Table 3. Screening criteria for residential developments in the EIA framework. Source: Martínez Orozco (2006).

In any case and although the EIA screening process varies significantly among countries (Martínez Orozco, 2006), residential construction projects are hardly ever subjected to an EIA (Table 3).

Although it has been recognized that proper design in eliminating and/or minimizing environmental hazards for contractors is vital to improved EM (Trethewy et al., 2003; Eom and Paek, 2009), no practical approaches have been found in the existing literature, excepting those published within the framework of this dissertation (Gangolells et al., 2007; Gangolells et al., 2009).

3.3.2 Addressing potential on-site environmental impacts in the construction planning stage

In any case, the EIA process presents guidelines for project pollution reduction planning taking into account the overall project lifecycle so it cannot provide overall environmental assessment tools to contractors in the pre-construction and construction stages (Eom and Paek, 2009).

According to Dione et al. (2005) and once the detailed design is finished, the contractor has two basic options for dealing with potential environmental risks to the project: to identify, assess, and mitigate risks early in the project's life to minimize the environmental impact related to the execution of construction projects, or to insure the project from known and/or unknown environmental risks. Obviously, the first option may be viewed as the safest alternative. Within the context of environmental disputes on construction, Eom and Paek (2009) argue that it is possible to suggest a risk management approach to resolve civil appeals that results from environmental pollution at construction sites in the pre-construction and construction stages.

According to Chen and Li (2006), there have been few studies on integrating aspects of EM in the construction planning stage in particular. Moreover, current approaches to environmental control and management are highly qualitative (Chen and Wong, 2005). A search of the Civil Engineering Database of the American Society for Civil Engineering and the Ei Compendex database found that only 2% of all papers on EM in construction provide quantitative methods (Chen and Wong, 2005).

Of the papers providing such methods, the approaches of Tam et al. (2004a), Shen et al. (2005), Eom and Paek (2009), Li et al. (2005), Cheung et al. (2004b); Tam et al. (2006a), Chen et al. (2000), Chen et al. (2004) and Chen et al. (2005) are among the most noteworthy.

Tam et al. (2004a) proposed a system called 'green construction assessment for construction', which serves as an assessment tool for construction activities in measuring environmental performance. This method analyses and foresees the performance trend and provides a consistent basis for comparisons, eco-labelling and environmental benchmarking among companies and construction sites. Shen et al. (2005) presented a scoring method for measuring the environmental performance done by a contractor through calculating the contractor's environmental performance score. However, in both methods construction impacts are assessed by the presence or absence of environmental protocols so environmental impacts are not assessed in a correct manner. In addition, the aforementioned methods do not include aspects related to the context of the building.

Eom and Paek (2009) developed an environmental risk index model for general contractors to minimize third-party environmental disputes at construction sites using information obtained from an on-site environmental risk evaluation process. In this case, risk factors were extracted from an analysis of five previous research results and in-depth discussions with three environmental construction specialists. The Environmental Risk Index (ERI) was determined based on the site engineer's judgement.

Li et al. (2005) gave a brief overview of an environmental performance assessment quantitative framework applicable to the construction stage. The authors suggested a tool for identifying and assessing environmental factors related to the construction phase based on the application of the traditional Life Cycle Assessment in construction unit procedures.

Cheung et al. (2004b) proposed a conceptual framework of a web-based environmental performance assessment system, called the WePass, which provides an instant online assessment of how well a construction site performs environmentally. In this case, not only the list of parameters to measure and control the environmental performance is not exhaustive, but also most of them are qualitative in nature so assessments are taken by means of the user giving score. Tam et al. (2006a) proposed three key output indicators namely, (i) regulatory compliance, (ii) auditing activities and, (iii) resource consumption together with nine sub-indicators. On the basis of their relative importance, the authors found that the top five sub-indicators were (i) fines and penalties, (ii) complaints or warnings, (iii) non-compliance records of inspection, (iv) non-conformance reports, and (v) reports of marginal cases put under observations. However, both aforementioned methods cannot be used to forecast potential environmental impacts prior to the construction stage.

Especially worthwhile is the Construction Pollution Index (CPI) method, developed by Chen et al. (2000), which has proved to be an efficient means of quantitatively evaluating the pollution and hazard levels of construction processes and projects. The Construction Pollution Index of an urban construction project is measured taking into account not only the duration of a construction operation that generates a hazard but also magnitude of the hazard (Chen et al., 2000; Chen et al., 2004). The magnitude of the hazard, which is quantitatively predefined by experts, must be set not only for each construction operation but also for each related environmental impact. In case no data are available, the magnitude of the hazard has to be decided based on the users' experience.

Chen et al. (2005) determined how to select the best construction plan by classifying the adverse environmental impact of construction operations/activities using the EnvironalPlanning method. However, subjective judgements often influence the accuracy of this method.

3.4 Integrating aspects of health and safety management in the pre-construction stages

3.4.1 Addressing construction worker safety in the design stage

The inclusion of health and safety issues during the design stage of the construction project is a consequence of the existing requirement of developing and submitting a project-specific occupational health and safety study. Since the adoption of the Royal Decree 1627/1997 (transposition of Directive 92/57/EEC), Spanish building designers are legally required to consider working conditions in their designs. However, previous studies have shown that designers in general—not just in the construction industry—fall short of satisfying this obligation (Behm, 2005; Fadier and De la Garza, 2006; Frijters and Swuste, 2008). Although health and safety studies could be a valuable tool for identifying and controlling construction health and safety risks, they often include generic risk assessments (Baxendale and Jones, 2000) and a repository of prevention measures that clearly diminish their effectiveness. According to Cameron and Hare (2008), both the existing literature and statistics support the notion that complying with health and safety regulations related to document completion is perceived as another layer of bureaucracy, requiring voluminous amounts of paper-work, produced for the sake of legislation and designed purely to satisfy the regulation in a back-covering exercise.

However, research conducted by Behm (2005) and Gambatese et al. (2008) demonstrated that 42.0% of construction fatalities were linked to the design, therefore it is clear that designers, architects and structural engineers have an influence on the health and safety of building site employees (Gambatese and Hinze, 1999; Behm, 2005; Frijters and Swuste, 2008; Gambatese et al., 2008; Toole and Gambatese, 2008).

In recent years, academics and professionals have focused on the concept of Construction Hazards Prevention through Design (CHPtD), in which engineers and architects explicitly consider, during the design process, the safety of construction workers (Toole and Gambatese, 2008). As noted by Toole and Gambatese (2008), even though articles on CHPtD have appeared in top construction journals, the literature has not yet addressed the technical principles underlying CHPtD in order to help designers better perform CHPtD and to facilitate the development of additional CHPtD tools. Additional tools and processes are needed in order to assist architects and design engineers with hazard recognition and design optimization (Gambatese, 2008).

Up until now, most publications on this subject have offered solutions that can be directly implemented and checklists for the subsequent monitoring of the design. Precise advice of this sort inhibits the designer's creative process and hampers the usual design process (Frijters and Swuste, 2008).

Other authors have developed a repository with design suggestions for improving construction worker safety while in the design phase. Gambatese and Hinze (1999) compiled and developed good practices with the aim of incorporating them into the knowledge database of a computer program entitled 'Design for Construction Safety ToolBox'.

Even so, there has been little research on how health and safety aspects can be interactively integrated during the design phase. Of the papers that have provided such methods, the approaches of Imriyas (2009) and Seo and Choi (2008) are among the most noteworthy; however, subjective judgements often influence their accuracy.

Seo and Choi (2008) developed a risk-based safety impact assessment methodology for underground construction projects in the design phase. The methodology can be summarized as the identification and evaluation of construction risk events that originate from the design and/or planning outputs (based on the subjective measurement of the frequency of the risk events and the magnitude of the accident caused by them), and the development of a checklist which links identified risks and design items.

Research undertaken by Imriyas (2009) within the area of workers' compensation insurance also included the computation of the Project Hazard Index and the Project Safety Index. The Project Hazard Index, or in other words, the hazard level in a project, is assessed by scrutinising its attributes with a rating mechanism. The Project Safety Index portrays the effectiveness of the site safety management and requires an exhaustive safety audit, which is supported by a guide based again on a rating mechanism developed by the authors.

Especially worthwhile is the method developed by Frijters and Swuste (2008), which has proved to be an objective, albeit labour-intensive, way of integrating safety aspects into the design process. The devised method helps designers to choose between alternative building elements on the basis of their risk level, which is calculated by counting the amount of working hours (understood as the exposure to risk) in a specific risk level (depending on the probability of the hazard occurring and the consequences of that hazard) (Frijters and Swuste, 2008). In this case, the exposure to risk is determined by calculating the total duration of the construction activities, underestimating other factors that may affect the exposure to a risk such as the density of hazards or the amount of work, which can be made at different speeds.

3.4.2 Addressing construction worker safety in the construction planning stage

Some previous authors state that formal identification of hazards in the workplace is one of the foundations of successful safety management (Trethewy et al., 2003; Carter and Smith, 2006); unidentified hazards present the most unmanageable risks (Carter and Smith, 2006). Similarly to the health and safety studies, some authors state that most contractors see their health and safety plans, which must include full risk assessment, as merely a burdensome requirement that they must fulfil in order to avoid government fines. As a result, they often use non-particularized health and safety plans or neglect their proper implementation (Wang et al., 2006; Saurin et al., 2008).

Empirical results from Carter and Smith (2006) indicate that hazard identification levels are far from ideal. The principal barrier to improvement in this key area is that most contractors lack the resources, knowledge or willingness to adequately identify hazards in a formal (documented) way (Trethewy et al., 2003). The subjective nature of hazard identification and risk assessment, the reliance upon tacit knowledge, and a lack of standardized approach are also recognized as barriers to improving hazard identification by Carter and Smith (2006).

Earlier studies have indicated that safety planning and control methods need to be improved even beyond what is required by regulations and standards (Saurin et al. 2004). Moreover, some authors have also argued that health and safety matters should be addressed as an integral part of the project management rather than an add-on (Saurin et al., 2004; Hare et al., 2006; Cameron and Hare, 2008). Therefore, in order to effectively integrate safety planning there needs to be an existing formal planning process already in place. In this sense, Cameron and Hare (2008) showed how health and safety planning and control could be integrated within existing project management activities as option evaluation charts, health and safety milestones, integrated project risk registers, responsibility charts, hazard ID workshops, red-amber-green lists or design change controls.

Carter and Smith (2006) developed an option evaluation chart where different alternatives are investigated in terms of how they impact on the health and safety domain. Specifically, they presented an Information Technology tool for construction project safety management designed to help construction personnel develop method statements with improved levels of hazard identification (Carter and Smith, 2006). The tool is intended to present the user with the best knowledge available at that time upon which to base decisions but the user can also estimate risk and add, edit or delete possible events and control measures to the existing lists.

Wang et al. (2006) proposed a method to include activities required for the management of health and safety risks within the linked bar chart of the project as health and safety milestones. Specifically, the degree of hazard of each activity in a construction project is evaluated; and this evaluation information is attached to the project network schedule. As stated by Wang et al. (2006), the model inputs are designed to be qualitative, which may affect the objectivity of the proposed method. The implementation of the model is also found to be time-consuming.

Saurin et al. (2004) devised a model to integrate safety into three hierarchical levels (namely, long-term, medium-term, and short-term) of production planning. Long-term safety planning, developed before starting construction, included a preliminary hazard analysis of construction processes. However, in this study no formal risk evaluation was reported. The long-term plans were updated and detailed at both medium (tri-weekly) and short-term (daily or weekly) planning levels. During the look-ahead planning, safety constraints were analysed and construction methods were further detailed. Daily or weekly planning meetings involved several key stakeholders and safety and production performance measures were routinely presented and discussed. The safety control was performed by monitoring the degree in which work packages were safely carried out.

Along the line of safety monitoring, Cheung et al. (2004a) described a web-based system for monitoring and assessing construction safety and health performance, which can be used as a detector of potential risks and hazards and as a warning sign to areas of construction activities that require immediate corrective action. Statistical parameters (number of accidents reported, number of man-days lost, etc.), functional parameters (non-conformance activities such as reports on safer work practices, tools and machinery, etc.), and human-related parameters (aspects related to education and training, inspection and complaints, and prosecution) are included within the method. These parameters can be quantitative or qualitative in nature. For qualitative parameters, measurements are taken by the user giving a 'score' for each parameter.

However, all the aforementioned methods still have the subjective nature of hazard identification and risk assessment, making the outcome of the process dependant on the people conducting it. Thus, the usefulness and effectiveness of the existing methods are hampered.

3.5 Summary

This chapter has provided an overview of the relevant research related to the integration of environmental and health and safety aspects during the pre-construction stages, identifying and examining shortcomings in the current approaches addressing the potential on-site environmental impacts and construction workers' safety in both the design and planning stages. This chapter serves to provide a foundation from which to learn, and to build upon, ensuring the research conducted for this thesis adds to rather than duplicates existing or other ongoing work.

Construction project performance has traditionally been measured in terms of time, cost and quality. Lately, the environment has been considered the fourth dimension (Shen and Zhang, 1999) mainly due to its recognised environmental impact both in terms of construction and building operation (Ding, 2008). However, most prior construction research attention has been focused on the evaluation of the environmental performance during building operation (Cole, 2000). The limited attention given to the impact of on-site construction is a consequence of a perceived relatively lower significance of construction impacts compared with the lifecycle impacts associated with the building operation and its inherent temporality (Cole, 2000). Nevertheless and due to the fact that the environmental impacts of construction activities have never been adequately quantified, the assumption that the effects of construction are negligible in comparison with the building phases is only a supposition (Sharrard et al., 2007).

Additionally, construction industry is, by its nature, dangerous and consequently, occupational health and safety is a major issue in construction sites. In fact, the construction sector has the highest Fatal Accident Rate per 100,000 workers both in the United States and Spain (Camino et al., 2008).

Decisions made during initial stages of a construction project have a long-lasting effect on the performance of the resulting building (Papamichael, 2000) but also may have consequences during the construction stage. Therefore, predicting and assessing them provide the basis for consistent decisions that may affect on-site environmental and health and safety performance.

However, designers are not legally required to consider the potential on-site environmental impact in their designs as residential construction projects are hardly ever subjected to the EIA Directive. Although it has been recognized that proper design in eliminating and/or minimizing environmental hazards for contractors is vital to improved EM (Trethewy et al., 2003; Eom and Paek, 2009), no practical approaches have been found in the existing literature.

According to Chen and Li (2006), there have been few research projects on integrating aspects of EM in the construction planning stage in particular. Moreover, current approaches to environmental control and management are highly qualitative (Chen et al., 2005). Of the papers providing such methods, the approaches of Tam et al. (2004a), Shen et al. (2005), Eom and Paek (2009), Li et al. (2005), Cheung et al. (2004b); Tam et al. (2006a), Chen et al. (2000), Chen et al. (2004) and Chen et al. (2005) are among the most noteworthy. However, some of these methods assess the construction impact by the presence or absence of environmental protocols. In other cases, methods are arbitrary and incomplete in their selection of environmental impacts. In addition, they do not include aspects on contextual issues that relate to site selection and building location and, in general, subjective judgements influence their accuracy. Despite these studies, a survey conducted among construction companies by Dione et al. (2005) to assess current risk-management practices in the construction industry shows that although many companies are concerned about the possible implications of environmental risks to their projects, there still needs to be more emphasis on the identification and mitigation of these risks. The authors also highlight the need to have a comprehensive framework to properly identify and develop an action plan for environmentally related risk issues (Dione et al., 2005).

Designers play a real role in influencing construction worker safety as they influence many decisions about how construction tasks are undertaken (Gambatese and Hinze, 1999). Although regulations have imposed an obligation on designers to address safety during the construction phase, they often include generic risk assessments (Baxendale and Jones, 2000) and a repository of prevention measures that clearly

diminish their effectiveness. In recent years, academics and professionals have focused on the concept of Construction Hazards Prevention through Design (CHPtD), however the literature has not yet addressed its technical principles in order to help designers better perform CHPtD and to facilitate the development of additional CHPtD tools (Toole and Gambatese, 2008). Of the papers that have provided such tools, the approaches of Imriyas (2009), Seo and Choi (2008) and Frijters and Swuste (2008) are among the most noteworthy; however, in some cases, subjective judgements influence their accuracy. Therefore, additional tools and processes are needed in order to assist architects and design engineers with hazard recognition and design optimization (Gambatese, 2008).

Several authors have consistently found that safety planning and control is one of the critical measures required to achieve a zero accident target (Saurin et al., 2004) as design decisions are often made upstream in the planning process before contractors carry out their work (Trethewy et al., 2003). However and as well as in the design stage, current legal approaches to planning for health and safety in the construction industry have been criticised for being bureaucratic and irrelevant (Cameron and Hare, 2008). Empirical results from Carter and Smith (2006) indicate that hazard identification levels are far from ideal. The main barriers to improvement in this key area are, among others, the lack of resources and the knowledge or willingness to adequately identify hazards in a formal (documented) way (Trethewy et al., 2003). Earlier studies have indicated that safety planning and control methods need to be improved even beyond what is required by regulations and standards (Saurin et al. 2004). Although some authors have addressed construction worker safety in the construction planning stage (Carter and Smith, 2001; Wang et al., 2006; Saurin et al., 2004, Cheung et al., 2004a), hazard identification and risk assessment still have a high level of subjectivity so its usefulness and effectiveness is hampered.

3.6 Implication of the results

The primary aim of this dissertation is to provide an effective way of integrating currently separate MSs for environmental and health and safety management in construction companies. The proposed methodology will contribute to the overcoming of the main obstacles related to the actual implementation process of integrated environmental and health and safety management systems in construction companies. Establishing the necessary basis and criteria to identify, assess and control environmental impacts and health and safety risks related to the construction process of residential buildings will obviously improve the understanding of how best to integrate the different MSs, especially during risk identification, assessment and control.

Focusing on risk identification and assessment, this dissertation will deal with the shortcomings of the current approaches addressing potential on-site environmental impacts and construction workers' safety in both the design and construction planning stages. As discussed before, and although it has been recognized that proper design is vital to improved EM, the methodology developed within this dissertation will be the first approach integrating aspects of environmental management during the design stage. Unlike other existing approaches focused on the planning stage, the assessment of potential on-site environmental impacts will be mostly quantitative and it will also include aspects related to local surroundings. Current approaches addressing construction worker safety during the design and planning stage are bureaucratic and irrelevant since they often include generic risk assessments and a repository of prevention measures. Apart from providing an innovative approach addressing the technical principles underlying CHPtD, the methodology developed within this thesis will provide a systematic way to conduct particularized assessments without inhibiting the designer's creative process. Other common shortcoming in current approaches addressing potential on-site environmental impacts and construction worker in both the design and planning stages is related to a high level of subjectivity during the assessment process. The proposed methodology overcomes this weakness by developing quantitative indicators based on data already available in the project documents.

Therefore, this dissertation will focus on the development of a quantitative methodology for predicting and assessing the environmental impacts and the health and safety risks associated with the construction of new residential buildings during the pre-construction stage. This methodology will provide designers with a risk-analysis-based way of evaluating the environmental and safety-related performance of their residential construction designs. This methodology will also help construction companies improve their on-site environmental and safety performance. Therefore, the proposed methodology will serve as an assessment tool for construction projects to measure the environmental and health and safety performance of their construction activities. It will also provide a consistent basis for comparisons and for future labelling and environmental and health and safety benchmarking among construction companies and construction sites.

Chapter 4

Development of a methodology for predicting and assessing environmental impacts and health and safety risks related to the construction process

4.1 Introduction

This chapter describes the work undertaken to meet the thesis' aim and individual objectives 3 and 4 stated in chapter 1. This chapter develops a methodology that provides an effective way of integrating currently separate MSs for environmental and health and safety management in construction companies. Assuming that integration is more than combining documentation of various systems, the proposed methodology uses risk as an integrating factor. Therefore, the methodology establishes the necessary basis and criteria to identify and assess environmental and health and safety risks related to the construction process of residential buildings. Besides helping construction companies to improve their on-site environmental and safety performance, this methodology also provides designers with a risk-analysis-

based way of evaluating the environmental and safety-related performance of their residential construction designs.

4.2 Methodological proposal

To effectively identify and assess environmental impacts and health and safety risks related to the construction of residential buildings, the following methodology is proposed:

1. Identification of environmental aspects and health and safety risks related to the construction process by means of a process-oriented approach.
2. Assessment of the environmental aspects and health and safety risks at the pre-construction stage.
    a. Development of indicators.
    b. Formulation of the significance limits.
    c. Determination of the significance of environmental impacts and health and safety risks of a construction project.

4.3 Identification of environmental aspects and health and safety risks

The identification of environmental aspects and health and safety risks related to the construction process is the first step of the proposed methodology. To do this, an exhaustive preliminary analysis with a process-oriented approach (Zobel and Burman, 2004) is carried out. First, the main processes are identified and divided into smaller process steps. Generic environmental aspects and health and safety risks are then identified.

4.3.1 Construction processes and activities initially considered

The main construction processes initially considered were (1) earthworks, (2) foundations, (3) structures, (4) roofs, (5) partitions and closures, (6) impermeable membranes, (7) insulations, (8) coatings, (9) pavements and (10) door and window closures according to the work sections included within the MetaBase database (ITeC, 2006) developed by the Catalan Institute of Construction Technology. These main construction processes were divided into smaller process steps as indicated by

Roberts and Robinson (1998). A total of 219 stages and activities were ultimately considered in this initial review (see figures 2 and 4 and subsection C1).

4.3.2 Environmental aspects initially considered

Many approaches have been described and proposed such as those ones provided by March (1992), Uher (1999), Chen et al. (2000), Cole (2000); Shen and Tam (2002); Cardoso (2005), Chen et al. (2005), Glass and Simmonds (2007), Sharrard et al. (2007) but the literature reaches no consensus regarding the environmental aspects associated with the construction process (see subsection 3.2 of this document). The Eco-Management and Audit Scheme (EMAS) provides a standardized and comprehensive list of environmental aspects that covers almost all of the aforementioned environmental aspects. Thus, EMAS was used as a guide to initially identify general environmental aspects (Fig. 2):

- Emissions to air;
- Releases to water;
- Avoidance, recycling, reuse, transportation and disposal of solid and other wastes, particularly hazardous wastes;
- Use and contamination of land;
- Use of natural resources and raw materials (including energy);
- Local issues (noise, vibration, odour, dust, visual appearance, etc.);
- Transport issues;
- Risks of environmental accidents and impacts arising, or likely to arise, as consequences of incidents, accidents and potential emergency situations;
- Effects on biodiversity.

In order to increase the level of precision, some of these environmental aspects were divided into more specific aspects (Lundberg et al., 2007). For example, the emission of greenhouse gases and the emission of volatile organic compounds (VOCs) and chlorofluorocarbons (CFCs) were considered, rather than just emissions to air.

4.3.3 Health and safety risks initially considered

As suggested by OHSAS 18001:2007 and OHSAS 18002:2008, this initial review uses reports of incidents and accidents that have occurred in other organizations (Fig. 4). Occupational Accident Report Form of the Spanish National Institute of Safety and Hygiene at Work was used as a guide in order to initially identify general safety risks:

- Falls between different levels;
- Falls at the same level;
- Falling objects due to crumble or collapse;
- Falling objects during handling;
- Objects falling from above;
- Stepping on objects;
- Hitting stationary objects;
- Hitting moving objects;
- Cuts or blows from objects and tools;
- Projection of fragments and particles;
- Becoming caught in or between objects;
- Becoming caught in dumped vehicles or machines;
- Overexertion, bad posture or repetitive motion;
- Exposure to extreme temperatures;
- Thermal contacts;
- Electric contacts;
- Exposure to harmful or toxic substances;
- Contact with caustic or corrosive substances;
- Exposure to radiation;
- Explosion;
- Fire;
- Injuries caused by a living being;
- Being hit or run over by vehicles;
- Traffic accidents;
- Natural causes;
- Others;
- Contact with chemical agents;
- Contact with physical agents;
- Contact with biological agents;
- Other types of disease, not classified elsewhere.

4.3.4 Determination of the environmental impact degree and the safety risk degree in a particular construction stage

4.3.4.1 Environmental domain

ISO 14004:2004 states that when criteria for significance are being established, an organization should consider (i) environmental criteria (such as scale, severity and duration of the impact, or type, size and frequency of an environmental aspect), (ii) applicable legal requirements (such as emission and discharge limits in permits or

regulations, etc.) and (iii) the concerns of internal and external interested parties (such as those related to organizational values, public image, etc.).

The difficulty and cost of changing the impact, the effect of change on other activities and processes, and the effect on the public image of the organization are considered business concerns. Some authors recommend excluding these criteria in the assessment process, arguing that they could lead to biased assessment results, or that the results might be misused (Põder, 2006).

According to Põder (2006), the evaluation of the significance of environmental impacts can be facilitated by considering spatial scale (the physical area influenced by a particular environmental aspect), severity (the combination of quantity, toxicity, affected volume, surface area and temporal extent), probability (the likelihood of the event causing the environmental impact) and duration (persistence) of the environmental impact (Fig. 7).

The severity of an environmental aspect varies with each specific building site, as there is a correlation between the magnitude of the project (quantities and toxicity of the materials involved, affected volume, or surface and temporal extent) and the effects caused. Other criteria do not depend on the construction project, so they can be used in this early stage to determine significant environmental aspects for every construction process: the scale of the impact, its probability of occurrence and its duration (Fig. 2, 3 and 7).

The nine environmental aspects initially considered were evaluated in terms of scale, duration and probability of occurrence for each construction stage. To diminish the intrusion of subjectivity during the identification of environmental aspects, a four-interval scale was developed for each of the three aforementioned components of significance. The spatial extent or zone of environmental impact influence can range from site-specific to regional or national; therefore, the scale for extent of impact is a progression through geographical units. The probability of occurrence refers to the frequency of the event that causes the environmental impact. This component of significance was scaled in a similar way and ranged from low probability (improbable) to relatively high probability (very likely or frequent). The duration of an environmental impact was scaled by taking into account the length of time that the environmental impact lasts. In this case, the duration of an environmental impact was described quantitatively in relation to the duration of the construction phase.

The scale of the impact, its duration and its probability of occurrence can be cross-referenced; for example, noise arising from the earthworks phase is site-specific, short-term and has a high probability of occurrence, whereas the generation of greenhouse gas emissions that contribute to climate change during the cladding

phase has an international scale and is persistent but has low probability of occurrence (excluding the transportation of materials). These three components of significance can therefore be represented graphically with the impact duration as the x-axis, the impact scale as the y-axis and the probability of occurrence as the z-axis. An impact is highly significant if it registers in the lower right part of the three graphs (Fig. 2 and 3).

In order to calculate the environmental impact degree of a specific construction stage, the four grade scales for the three components of significance are converted into numerical scales (Fig. 3). Unfortunately, the literature provides no suitable models on which to base such a scoring system, so the system shown in figure 2 and 3 was established. For the sake of simplicity, the environmental impact degree of a particular construction stage was obtained using the following expression:

$$ID_{Ei} = D_i \cdot S_i \cdot P_i \tag{1}$$

where ID_{Ei} denotes the environmental impact degree of a specific construction stage i. D_i denotes the impact duration, assumed to be 0 (none), 1 (shorter than the duration of the construction stage), 2 (equal to the duration of the construction stage) or 3 (greater than the duration of the construction stage). S_i corresponds to the impact scale, ranging from 0 (none), 1 (site and surrounding area), 2 (local and regional) to 3 (out of region). Finally, P_i denotes the probability of occurrence of the impact, assumed to be 0 (improbable), 1 (not very likely), 2 (likely) or 3 (very likely).

In this initial identification of environmental aspects, an environmental impact for a specific construction stage was considered significant if its degree was greater than 4. The resulting matrix allowed us to distinguish potential environmental impacts for each construction stage. In order to make future assessments controllable and effective, some environmental aspects were aggregated whereas others where disaggregated.

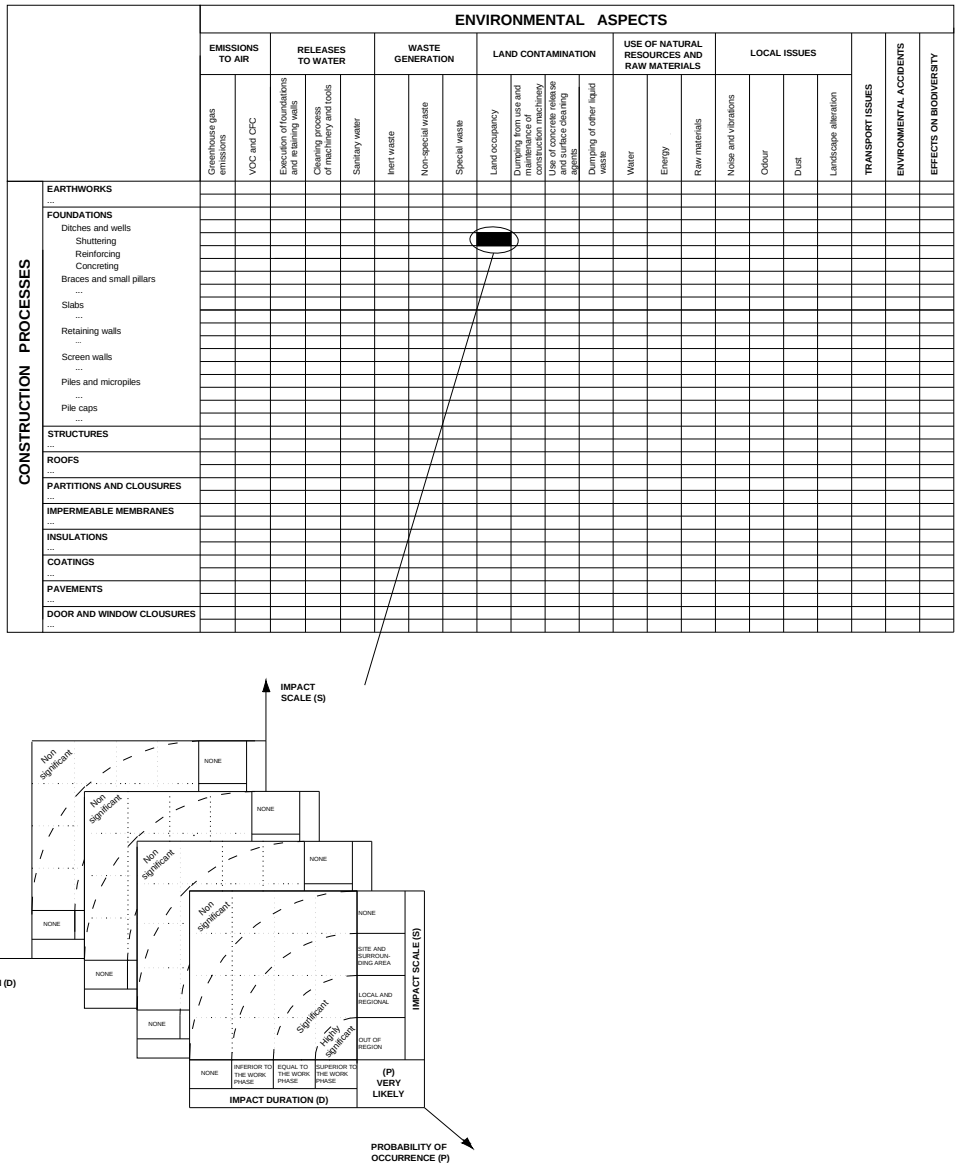

Fig. 2. Identification of environmental aspects in a process-oriented approach assessing probability of occurrence (P), impact duration (D) and impact scale (S).

Source: partially adapted from Johnston et al. (2000).

0	0	0	0	NONE	IMPACT SCALE (S)
0	0	0	0	SITE AND SURROUN-DING AREA	
0	0	0	0	LOCAL AND REGIONAL	
0	0	0	0	OUT OF REGION	
NONE	INFERIOR TO THE WORK PHASE	EQUAL TO THE WORK PHASE	SUPERIOR TO THE WORK PHASE	(P) IMPROBA-BLE	
IMPACT DURATION (D)					

0	0	0	0	NONE	IMPACT SCALE (S)
0	1	2	3	SITE AND SURROUN-DING AREA	
0	2	4	6	LOCAL AND REGIONAL	
0	3	6	9	OUT OF REGION	
NONE	INFERIOR TO THE WORK PHASE	EQUAL TO THE WORK PHASE	SUPERIOR TO THE WORK PHASE	(P) NOT VERY LIKELY	
IMPACT DURATION (D)					

0	0	0	0	NONE	IMPACT SCALE (S)
0	2	4	6	SITE AND SURROUN-DING AREA	
0	4	8	12	LOCAL AND REGIONAL	
0	6	12	18	OUT OF REGION	
NONE	INFERIOR TO THE WORK PHASE	EQUAL TO THE WORK PHASE	SUPERIOR TO THE WORK PHASE	(P) LIKELY	
IMPACT DURATION (D)					

0	0	0	0	NONE	IMPACT SCALE (S)
0	3	6	9	SITE AND SURROUN-DING AREA	
0	6	12	18	LOCAL AND REGIONAL	
0	9	18	27	OUT OF REGION	
NONE	INFERIOR TO THE WORK PHASE	EQUAL TO THE WORK PHASE	SUPERIOR TO THE WORK PHASE	(P) VERY LIKELY	
IMPACT DURATION (D)					

Fig. 3. Numerical scales for the three components of significance: probability of occurrence (P), impact duration (D) and impact scale (S).

Source: partially adapted from Johnston et al. (2000).

4.3.4.2 Health and safety domain

OHSAS 18001:2007 defines a risk as the combination of the likelihood of occurrence of a hazardous event and the severity of the injury or ill health that can be caused by the event. Consideration of risks in terms of the probability of their occurrence and the severity of their consequences provides the general rationale behind safety risk assessments (Carter and Smith, 2006). Probability (P) is defined as the likelihood of a hazard's potential being realized and initiating an incident or series of incidents that could result in harm or damage. Severity of consequences (C) is defined as the extent of harm or damage that could result from a hazard-related incident (Manuele, 2006).

Neither the probability nor the severity of consequences depend on the construction project, so they can be used in this early stage to determine significant risks that are common to every construction process (Fig. 4 and 7). The 30 health and safety risks initially considered were evaluated in terms of probability and severity of consequences. To reduce the intrusion of subjectivity during the identification of construction safety risks, a four-interval scale was developed for each of these evaluation components. The probability of occurrence ranges from low probability (improbable) to relatively high probability (very likely or frequent). The scale of probability was thus defined as a progression through the various levels of likelihood. The severity of consequences was rated by taking into account the extent of the damage that could result from an incident (none, minor, major or catastrophic).

Probability of occurrence and severity of consequences can be cross-referenced. For example, during the placement of in-situ concrete, stepping on objects has a high probability of occurrence but entails minor consequences, whereas becoming caught in a dumped vehicle or machine is improbable, but would result in fatal injuries if it were to happen. These two evaluation components can therefore be represented graphically with the probability of occurrence as the x-axis and the severity of consequences as the y-axis. A risk is highly significant if it is plotted in the lower right part of the graph (Fig. 4).

In order to calculate the safety risk degree of a specific construction stage, the four-grade scales for the two evaluation components are converted into numerical scales (Fig. 4). Unfortunately, the literature provides no suitable models on which to base such a scoring system, so the scoring system shown in figure 4 was established.

The significance rating of a safety risk in a particular construction stage was defined as follows:

$$RD_{Si} = P_i \cdot C_i \tag{2}$$

where RD_{Si} denotes the safety risk degree of a specific construction stage i. P_i represents the probability of risk occurrence, assumed to be 0 (improbable), 1 (not very likely), 3 (likely) or 5 (very likely). C_i corresponds to the severity of risk consequences, ranging from 0 (none), 1 (minor), 3 (major) to 5 (catastrophic).

During this initial review, a risk was considered significant in a specific construction stage when its degree was equal to or greater than 3. The resulting matrix allowed distinguishing potential safety risks for each construction stage. In order to make future assessments controllable and effective, most of the construction safety risks were aggregated.

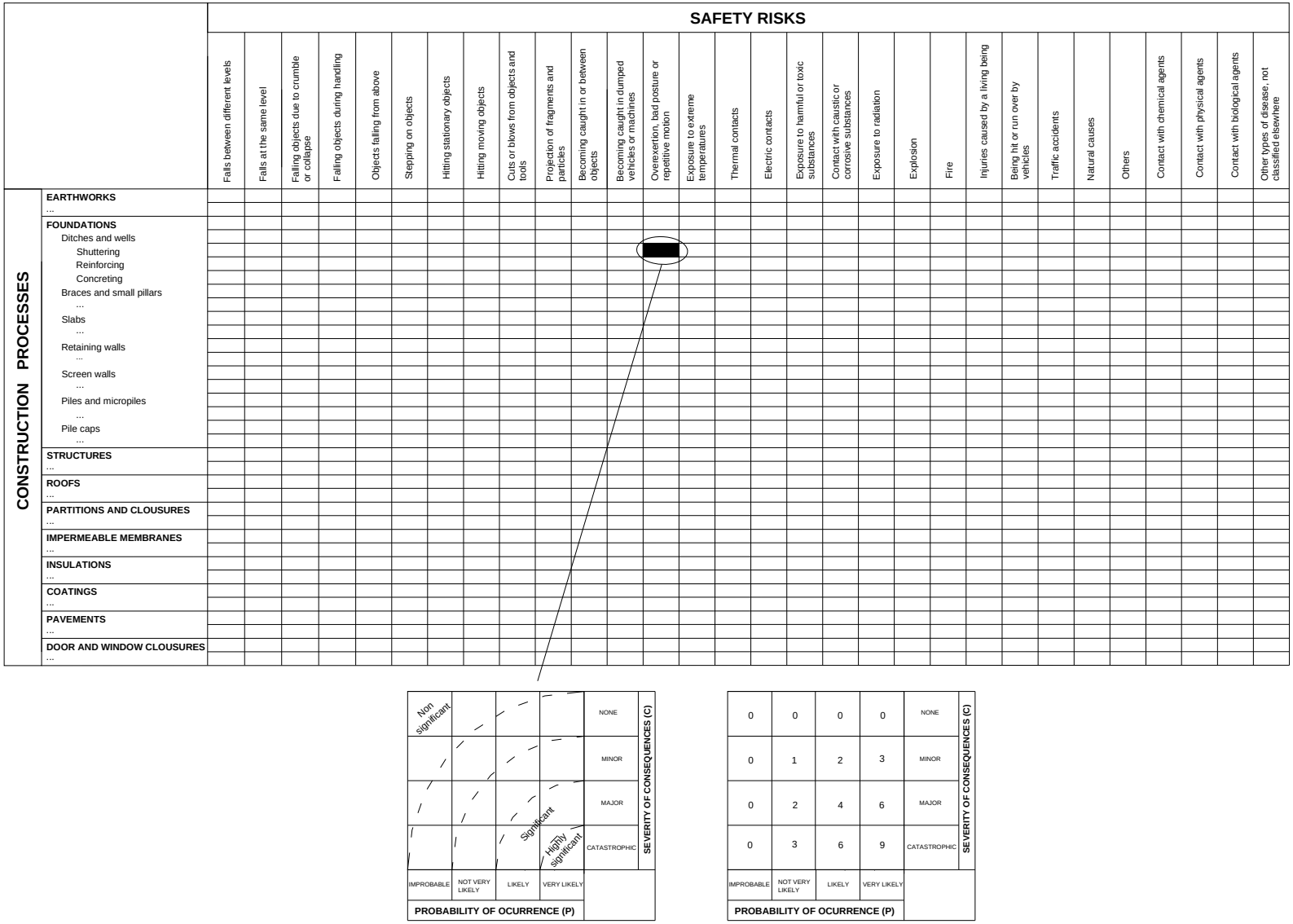

Fig. 4. Identification of construction health and safety risks in a process-oriented approach and numerical scales for the two components of significance: probability of occurrence (P) and severity of consequences (C).

Source: partially adapted from Johnston et al. (2000).

4.3.5 Summary of environmental aspects and health and safety risks related to the construction process

As a result of this process (Fig. 5), 37 significant environmental aspects for construction activities were obtained. The 'atmospheric emissions' category includes environmental aspects derived from the emission of greenhouse gases, VOCs and CFCs. All those environmental aspects with potential adverse impacts on the quality of surface water, groundwater or the sewage system were included in the 'water emissions' category. The methodology also includes all waste materials expected to be generated during construction: human waste, excavated material generated during earthworks and excess off-cuts of construction materials (reinforcement, concrete and formwork). Hazardous waste is also considered. The 'soil alteration' category includes all the aspects related to land occupancy and potential adverse impacts due to the dumping of pollutant liquids. Environmental aspects related to the use of resources (mainly water, electricity, fuel and raw materials) are also taken into account. Specific local issues such as suspended particles emission, dirtiness, noise, vibrations and visual impacts are also included in the methodology. Since construction work may also cause impacts on local traffic and transport, the methodology includes a category called 'transport issues'. The 'effects on biodiversity' category includes all aspects related to vegetation loss, loss of soil fertility and potential adverse impacts due to the interception of river beds. Risks of environmental accidents and impacts arising, or likely to arise, as consequences of incidents, accidents and potential emergency situations are also considered. Specific environmental aspects are listed in Table A.1.

The identification process also allowed obtaining 91 significant safety risks for construction activities aggregated in 24 different categories (Fig. 5). Obtained safety risks relate to falls (between different levels or at the same level), injuries from objects falling from above and injuries from falling objects (due to crumble or collapse, or handling). The methodology also includes categories for injuries from stepping on objects or injuries from hitting stationary or moving objects. Injuries from objects and tools, injuries from projection of fragments and particles or injuries from becoming caught (in or between objects or in dumped vehicles or machines) are also included within the methodology. Other safety risks are included within the categories of overexertion, exposure to extreme temperatures, thermal and electric contacts, exposure to harmful or toxic substances, contact with caustic or corrosive substances, exposure to radiation and fires and explosions. Injuries from being hit of run over by vehicles, injuries from traffic accidents or contact with chemical and physical agents are also considered. Table A.2 lists these specific construction safety risks.

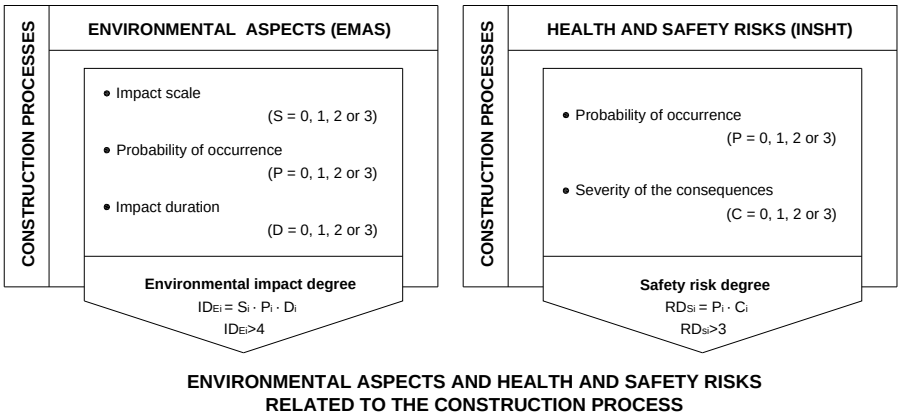

Fig. 5. Overview of the identification process of environmental aspects and health and safety risks in a process-oriented approach.

Some of these risks apply to both the environmental and the health and safety domains. Environmental aspects related to dust generation, which are classified in the environmental category of 'local issues', also belong to the safety category of 'contact with chemical agents'. In the same way, the generation of noise and vibrations due to site activities, classified into the environmental category of 'local issues', also fits in with the safety category of 'contact with physical agents'. All those environmental aspects related to risks of environmental accidents and impacts arising, or likely to arise, as consequences of incidents, accidents and potential emergency situations have also a correspondence within the safety domain, specifically in the 'fires and explosions category'. Figure 6 and table A.3 list those risks that apply to both the environmental and the health and safety domain.

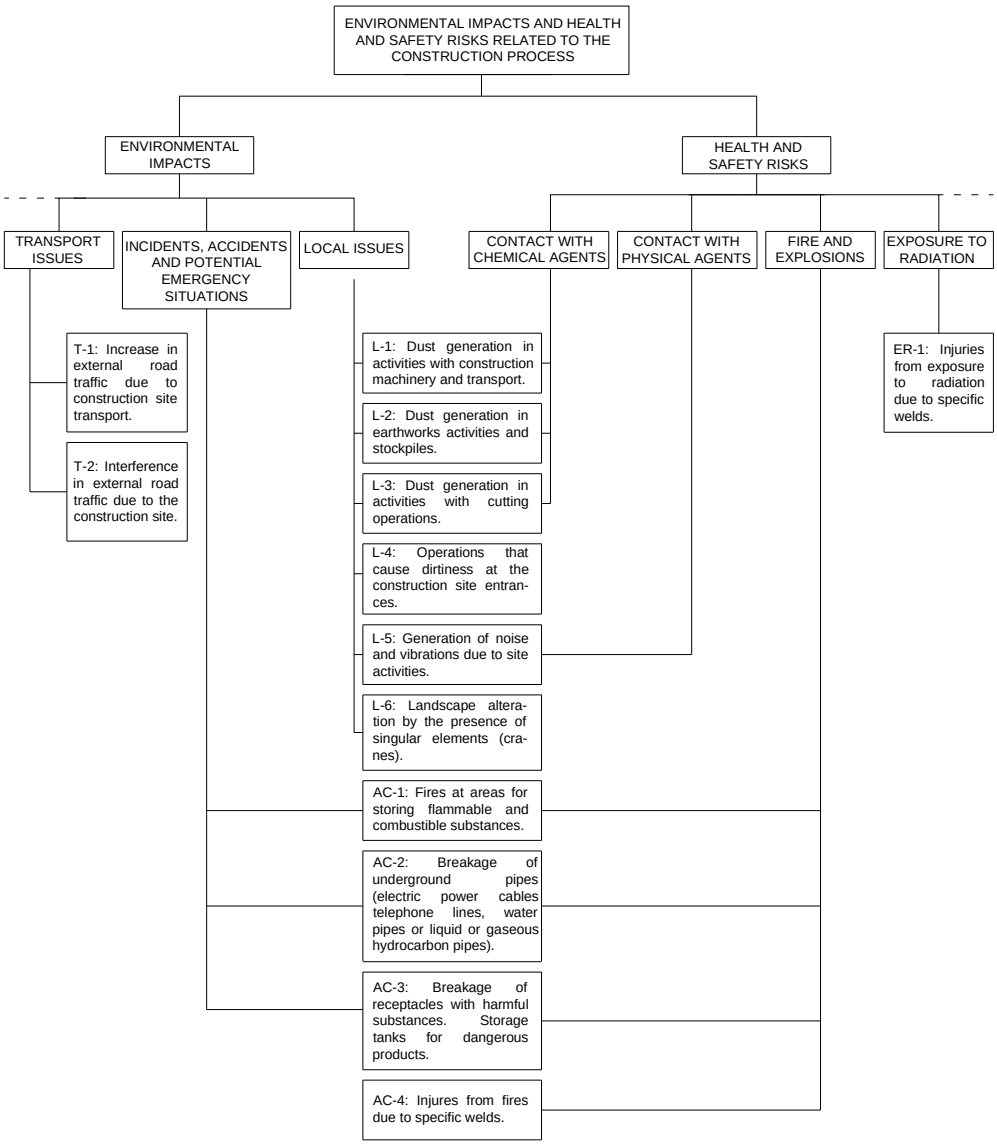

Fig. 6. Common environmental aspects and health and safety risks related to the construction process.

4.4 Assessment of the environmental aspects and health and safety risks at the pre-construction stage

When the environmental aspects were identified during the initial review, only environmental criteria not dependent on the construction project were analysed (scale, probability and duration of the impact). Therefore, in this stage we had to consider any remaining components of significance that matched those that depended on each specific building site: severity of consequences, applicable legal requirements and concerns of interested parties (Fig. 7).

In order to assess impact severity and applicable legal requirements, a matrix model with several assessment criteria to assess the impact magnitude (MG) for each environmental aspect was developed. The impact magnitude parameter (MG) tries to assess the relevance of each environmental aspect in quantitative terms and without taking into account the environment's fragility. Therefore, this parameter estimates the combination of the total quantity of pollutant elements, affected volume or surface, and the impacting action duration. So as to include detailed criteria to help decision-makers determine whether the impact magnitude (MG) is significant, a four-interval scale was developed: non-existent impacts, non-significant impacts, mediumly significant impacts and extremely significant impacts (Table 4). To help achieve a homogeneous outcome, numerical limits were established between the four categories (Table 4).

Impact magnitude (MG_j)	**Score**
Non-existent impacts	0
Non-significant impacts	1
Mediumly significant impacts	3
Extremely significant impacts	5

Table 4. Scoring system for impact magnitude (MG_j).

So as to assess concerns of interested parties, the interaction between an activity and its environment (and vice-versa) is considered. Therefore, the environment parameter (EN) considers the sensitivity of the location or receptor. Buildings are clearly connected to their surroundings and therefore without reference to their wider context, the significance assessment of an environmental impact would be

biased. In order to include detailed criteria to help people determine how sensitive the environment (EN) is, a three-interval scale was developed: non-sensitive environment**,** mediumly sensitive environment and extremely sensitive environment (table 5). In this case, to help achieve a homogeneous outcome, numerical limits were also established between the three categories.

Environment (EN_j)	**Score**
Non-sensitive environment	1
Mediumly sensitive environment	3
Extremely sensitive environment	5

Table 5. Scoring system for environment (EN_j).

Therefore, all remaining components of significance in the environmental domain (severity, applicable legal requirements and concerns of interested parties) were thus included in the methodology (Fig. 7).

Moving to the health and safety domain, it is widely recognised that the immediate causes of accidents include factors that can cause an accident physically and directly, whether the accident happens or not. These causes include unsafe conditions and unsafe acts (Jannadi and Assaf, 1998; Fang et al., 2004). Unsafe conditions are physical conditions which, if left uncorrected, are likely to cause an accident. To improve safety at the work site, such conditions must be detected before an accident occurs (Jannadi and Assaf, 1998). Unsafe acts are not considered in this dissertation because they cannot be assessed during the study, design, planning or preparation stages of the construction project. In order to assess unsafe conditions and according to the Fine method, the exposure parameter was considered, understood as the frequency of occurrence of the hazard-event (Fine and Kinney, 1971) or the quantitative or semi-quantitative estimation of potentially hazardous situations to which workers are exposed during the construction process. In contrast to the evaluation components mentioned above (probability of occurrence and severity of consequences), this component depends on the characteristics of each construction project (Fig. 7).

So as to include detailed criteria to help people conducting the assessment determine whether the risk exposure (EX) is significant, a four-interval scale was developed: no exposure, non-significant exposure, mediumly significant exposure and extremely significant exposure (Table 6). To help achieve a homogeneous outcome, numerical limits were established between the four categories (Table 6).

Risk exposure (EX_j)	**Score**
No exposure	0
Non-significant exposure	1
Mediumly significant exposure	9
Extremely significant exposure	25

Table 6. Scoring system for risk exposure (EX_j).

In this way, all components of significance in the health and safety domain were thus included in the methodology (Fig. 7).

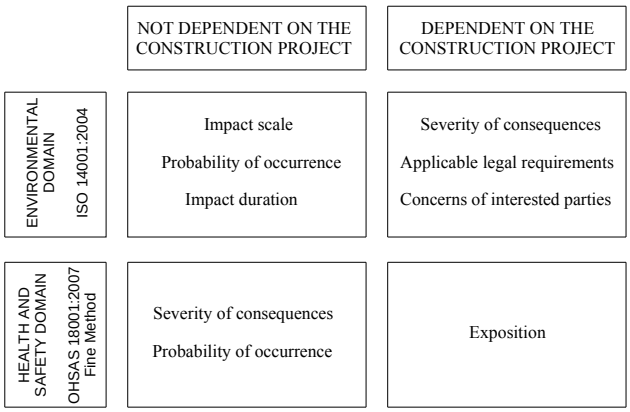

Fig. 7. Overview of the components of significance for the environmental and the health and safety domains.

4.4.1 Determining indicators

Indicators for the assessment of environmental and health and safety risks significance (referring to impact magnitude, environment and safety risk exposure) were developed. These indicators were based on particular observable or measurable characteristics of a construction project and represented, in all cases, the variable that was being measured (impact magnitude, environment or safety risk exposure). Because this methodology is intended to objectively assess environmental impacts and construction safety risks in advance, indicators were always based on the

information contained in the construction project documents (e.g. building specifications, drawings, bill of quantities, health and safety plan, and budget).

The principles for deriving environmental indicators laid down in the ISO 14031:1999 standard were carefully studied so as to develop comparable, target-oriented environmental indicators that were balanced, continuous, frequential and comprehensible (International Standard Organization, 1999). Tables A.1 and A.3 include the environmental indicators.

Just as in the environmental domain, when developing safety indicators, the traits highlighted by Manuele (2003) were taken into account. Therefore, most of the developed safety indicators are objectively quantifiable, which helps make the outcome of the process independent of the people who conduct the assessment. From an administrative point of view, they are practical and do not involve a great deal of time. They are sufficiently sensitive to detect changes in a process, but stable if there is no change, i.e. they produce the same results in successive applications to a single situation. Tables A.2 and A.3 list the safety indicators.

The developed indicators mainly focus on assessing the environmental and safety performance of construction sites and their corresponding processes and operations. However, the design phase is also included, due to its significance in the overall environmental and safety performance of a project.

In order to assess the magnitude of environmental aspects, direct environmental indicators were proposed whenever possible, as they are unequivocal. For example, water consumption (expressed in m^3) is a good direct environmental indicator of the environmental aspect 'Water consumption during the construction process', which is included in the 'resource consumption' category. This parameter can be assessed based on the information contained in the Bill of Quantities.

However, sometimes direct indicators cannot be used in this methodology. According to Johnston (2000), there is no universal measurement for widely different impacts. Furthermore, the developed methodology is intended to assess the significance of the environmental aspects derived from the building construction process in advance (based on the construction project documents), which makes it much more difficult to find direct environmental indicators. When direct environmental indicators cannot be used, indirect indicators (other parameters that can be measured based on the project documents) are proposed. For example, the quantity of synthetic paints and varnishes used at the construction site (or percentage of the total) is a good indirect indicator of an environmental aspect included in the 'atmospheric emissions' category (emissions of VOCs and CFCs). This parameter can be obtained from the Bill of Quantities. Likewise, the number of construction

workers is an indirect environmental indicator for the environmental aspect of generation of municipal waste at the construction site (domestic waste such as food, packages, etc.). This parameter can easily be found in the project's Health and Safety Plan. Since indirect indicators are related to the environmental aspect being assessed, they make it possible to obtain an admissible order of magnitude, thereby ensuring the objectivity of the evaluation process. Indirect indicators allow an acceptable approximation without taking up a great deal of time.

Although environmental indicators can sometimes be expressed as direct measurements, most are expressed as relative values (input figures are referenced to m^2 of floor area, assuming the floor area of a building as the sum of the area of each floor of the building measured to the outer surface of the outer walls). The use of environmental indicators per m^2 of floor area avoids penalties due to the size of a construction project. For the same reason, other environmental indicators are expressed as a percentage of a total amount. Aggregated depictions, in which figures of the same units are summed over more than one process step, are also used. Tables A.1 and A.3 show the developed environmental indicators and corresponding information sources.

On the other hand, the environment parameter (EN) considers the sensitivity of the location or receptor. So as to assess it, 23 indicators (mostly qualitative) had to be proposed. Specifically, qualitative assessment indicators were used in those cases where the data for the more desirable quantitative assessment is either not available or prohibitively expensive to acquire (Cole, 1999).

Contextual issues that relate to site selection and building location have been taken into account such as urban/rural areas, population, distance to neighbouring town centers, nearby occupied buildings, forested areas or other high fire risk areas, density of surrounding traffic roads, etc. Contextual issues that relate to proximity to amenities (fires stations, hospitals, airports, etc.) have also been included within the environment parameter. By way of example and from an environmental point of view, impact L-5 (generation of noise and vibrations due to site activities) should not be assigned the same relevance in an industrial area as in a residential area with hospitals or schools nearby. The ecological context also plays an important role in the sense that a small development proposal in an ecologically sensitive environment may be considered to have a more significant impact than a far larger development located in a more robust setting. Archaeological and historical artistic features have also been considered. When assessing the environment parameter, specific provisions stated in the construction project documents to protect the environment have also been included such as the existence of in-situ waterproof decanting pounds, watertight tanks, septic tanks or connection to sewage system for construction water treatment. By way of example and within the category of waste

generation, the environment parameter considers possible planning for in-situ reuse of waste materials or setting up a selective waste collection plan to later delivery to an authorized manager. Tables A.4 and A.5 show the developed indicators.

Moving to the health and safety domain, in order to assess construction safety risk exposure, mostly indirect safety indicators had to be proposed. Some health and safety indicators are expressed in absolute terms, assuming that exposure to a particular health or safety risk is directly related to the volume of work. This is the case for the risk FH-6 (falls between different levels during work on door and window closures), which is measured by the absolute indicator 'number of balconies without boundary walls and windows in the building'. This parameter can be obtained from the Bill of Quantities. Other indicators are expressed in relative terms in order to measure the 'density of hazards' (depending on the case, input figures are referenced to m^2 of floor area, m^2 of roof area or m^2 of site occupation). The indicator for the health and safety risk FH-5 (falls between different levels during floor work) is a relative one: 'total perimeter of holes measuring more than 0.40 m^2 plus total perimeter of balconies without boundary walls per m^2 of floor area'. This parameter can easily be found in the project's drawings. Tables A.2 and A.3 show the developed safety indicators and corresponding information sources.

4.4.2 Obtaining significance limits

A common, but often unstated, baseline for assessment is a 'typical' or 'average' performance and, as such, recognition is given for better than 'industry norm' performance (Cole, 1999). Therefore, it was necessary to characterize current performance levels in construction projects. A statistical analysis of several construction projects allowed to define explicit reference levels for all indicators related to environmental impacts and health and safety risks. It was assumed that the statistical analysis of quantitative indicators from several new-start construction projects would result on a reference building characterized by industry benchmarks, providing a base for performance scoring that could be derived and stated with some confidence (Cole, 1999).

Thus, in order to establish numerical limits for the environmental domain (between non-existent impacts, non-significant impacts, mediumly significant impacts and extremely significant impacts) and for the safety domain (between no exposure, low exposure, significant exposure and high exposure to safety risks), 55 new-start construction projects were analysed. Of these projects, 25 were projects for the construction of between one and nine single-family houses. They varied in floor area from 245 to 4,868 m^2 ranging from one to four floors. The other 30 construction projects were for multi-family dwellings. They ranged in size from a small block of

three dwellings with a total floor area of 405 m^2 to a property development of 88 dwellings and a floor area of 13,781 m^2. They also ranged from three to seven levels above ground and from zero to two levels below ground.

Although most of the quantitative indicators were replicated with a normal distribution, the log-normal distribution probability density function suited some indicators, especially in projects for single-family houses. Table B.1 shows the estimated distribution for each of the quantitative indicators considered in this analysis, as well as the means and standard deviations of the corresponding distributions.

As a starting point, it was considered that a high proportion of construction projects involve a mediumly significant environmental impact and a mediumly significant exposure to safety risks. In order to establish upper and lower limits for mediumly significant environmental impacts and mediumly significant exposure to safety risks, a 68% confidence interval [μ-σ, μ+σ] was calculated for each indicator. Thus, if an environmental indicator is lower than μ-σ, the environmental aspect is considered non-significant. However, if the environmental indicator is higher than μ+σ, the environmental aspect is considered extremely significant. Environmental indicators within [μ-σ, μ+σ] are considered mediumly significant. In the same way, if a safety indicator was lower than μ-σ for a particular construction project, the exposure to the corresponding construction safety risk was considered non-significant. However, if the indicator was higher than μ+σ, the exposure to the corresponding risk was considered extremely significant. Safety indicators within [μ-σ, μ+σ] show mediumly significant exposure. Table B.1 also includes the upper and lower limits of the 68% confidence interval.

Unfortunately, not all of the environmental and safety indicators included in this methodology are quantitative. The significance limits for indicators expressed in qualitative terms such as indicators for SA-2 (use of concrete release agent at the construction site), L-5 (generation of noise and vibrations due to site activities), ET-1 (injuries from exposure to extreme temperatures) and CO-2 (injuries from becoming caught in or between objects during small demolition operations) were derived from previous experiences, giving greater care and precision to the description of the assessment scales.

4.4.3 Determining the significance of environmental impacts and health and safety risks

The significance of an environmental impact related to the construction process in a particular construction project was obtained using the following expression:

$$SG_{Ej} = MG_j \cdot EN_j \tag{3}$$

where SG_{Ej} denotes the significance of a particular environmental impact *j* in a specific construction project. MG_j denotes the impact magnitude, assumed to be 0 (non-existent impact), 1 (non-significant impact), 3 (mediumly significant impact), or 5 (extremely significant impact). EN_j corresponds to the sensitivity of the environment, ranging from 1 (non-sensitive environment), 3 (mediumly sensitive environment) to 5 (extremely sensitive environment).

In the safety domain, the significance of a safety risk related to the construction process in a particular construction project was obtained using the following expression:

$$SG_{Sj} = EX_j \tag{4}$$

where SG_{Sj} denotes the significance of a particular safety risk *j* in a specific construction project. EX_j denotes the risk exposure, assumed to be 0 (no exposure), 1 (non-significant exposure), 9 (mediumly significant exposure), or 25 (extremely significant exposure).

If the documents of a construction project lack the information needed to make a satisfactory appraisal of a certain environmental aspect, the environmental impact magnitude is automatically classified as extremely significant (MG_j=5) or the environment parameter is assumed to be extremely sensitive (EN_j=5). Just as in the environmental domain, within the safety domain and if there is no information to assess the exposure parameter, a high exposure to the safety risk (EX_j=25) is automatically assumed (worst case scenario).

Establishing the acceptability of a potential environmental impact or safety risk entails the definition of a threshold or quantitative criterion. In this case and if, after conducting the assessment, the significance of any environmental impact or safety risk is found to be higher than 9, actions to eliminate or reduce that impact or risk must be taken. This limit is the result of considering an intermediate situation for both the environmental domain (a mediumly significant impact in a mediumly sensitive environment) and the health and safety domain (a mediumly significant exposure). Actions to eliminate or reduce an impact or risk could include abandoning the project in part or in its entirety, starting a re-design process or providing a range of procedures for mitigating adverse environmental impacts or safety risks that can then be implemented during on-site construction activities. A framework for levels of acceptability is provided in the following table:

Level of acceptability	Significance	Actions to be taken
Unacceptable	$SG_{Ej} > 9$ $SG_{Sj} > 9$	Abandon project in part or in its entirety. Redesign project to avoid environmental impacts and safety risks. Provide on-site instructions to be implemented during on-site construction activities.
Acceptable	$SG_{Ej} \leq 9$ $SG_{Sj} \leq 9$	Depending on the case, impacts and risks may be acceptable if mitigation measures and operational controls are properly implemented.

Table 7. Level of acceptability for environmental impacts and health and safety risks.

The methodology assesses the overall environmental impact level and the overall safety risk level of a construction project as shown in (5) and (6).

$$R_E = \sum_{j=1}^{n} SG_{Ej} \tag{5}$$

where R_E is the overall environmental impact level of a construction project and SG_{Ej} designates the significance of a particular environmental impact *j* in a specific construction project.

$$R_S = \sum_{j=1}^{n} SG_{Sj} \tag{6}$$

where R_S is the overall safety risk level of a construction project and SG_{Sj} denotes the significance of a particular safety risk *j* in a specific construction project.

Obviously, the construction project with the highest sum is the project with the most significant environmental impact. Similarly, the construction project with the highest sum is considered to have the lowest safety level.

Figure 8 summarizes the methodology for predicting and assessing environmental impacts and safety risks related to the construction of residential buildings:

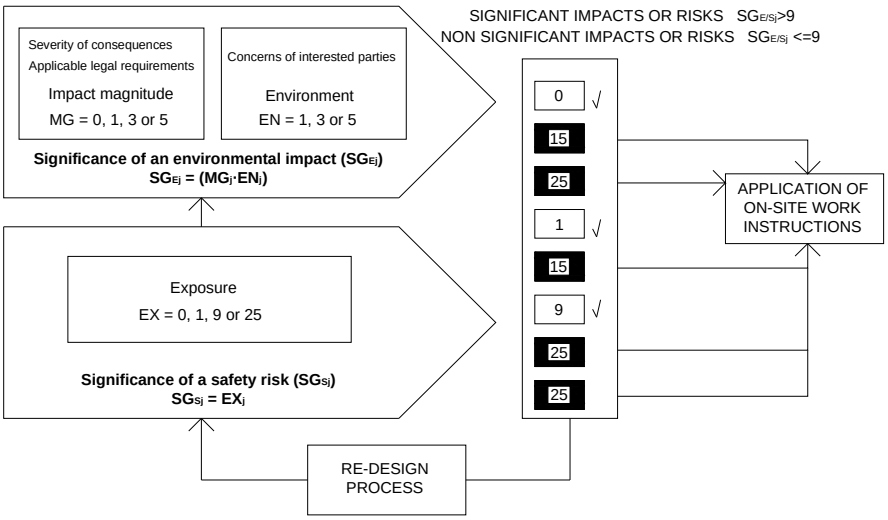

Fig. 8. Overview of a particular construction project assessment.

4.5 Web-based implementation system

The process of assessing a construction project using the presented methodology may involve a great amount of time. In order to reduce the time devoted to the assessment of each construction project, a web-based implementation tool has been developed.

The web-based interface is accessed via the internet domain address https://gric.upc.es/integracio/ (username: thesis; password: gangolells; role: designer). Figure 9 shows the access page.

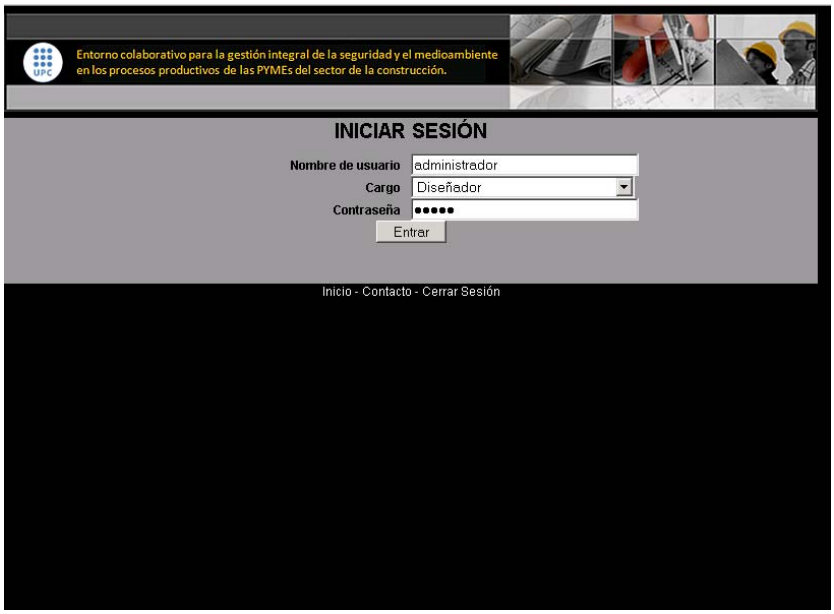

Fig. 9. Access to the web-based system.

The user registration function serves as an access control mechanism that prevents unauthorised users from entering and/or retrieving sensitive data. The role-based access control distinguishes different access rights. In this case, pre-defined roles are designers and site managers (or other people from the construction company involved in on-site environmental and health and safety management). After accessing the system, both roles will have the same possibilities, except for accessing the radial browser, which will only be accessible for site managers.

The web-based system includes three main modules. The first one is devoted to collecting and recording data, the second one conducts indicator calculations and the third one displays the obtained results, allowing its analysis by showing distribution charts.

4.5.1 Data input

After accessing the system by entering the correct username and password, the user can open a new project or retrieve an old one. The second option allows not only the

user check out any information related to a construction project already assessed but also to change some of the introduced values (Fig. 10).

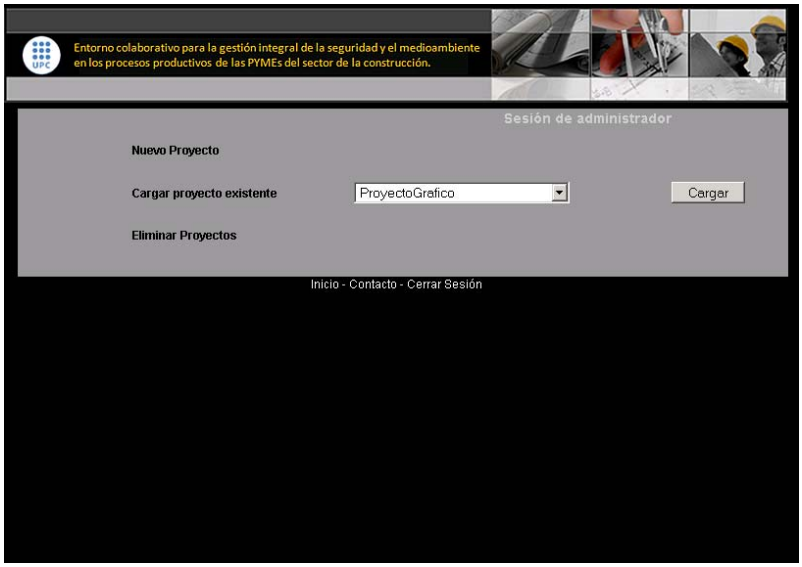

Fig. 10. Creating a new construction project assessment or loading an existing one.

In order to save time, computer-aided data entry forms have been designed. Data required for calculating both environmental and safety indicators (see tables A.1, A.2, A.3, A.4 and A.5) were the basis for the design and development of data-entry templates. The data-entry process was organised under 10 different subsections: general information (Fig. 11), site location (Fig. 12), phase works (Fig. 13), setting up, raw materials consumption (Fig. 14), waste management, site preparation, earthworks and foundations, structure (Fig. 15) and, closures and coatings (Fig. 16) .

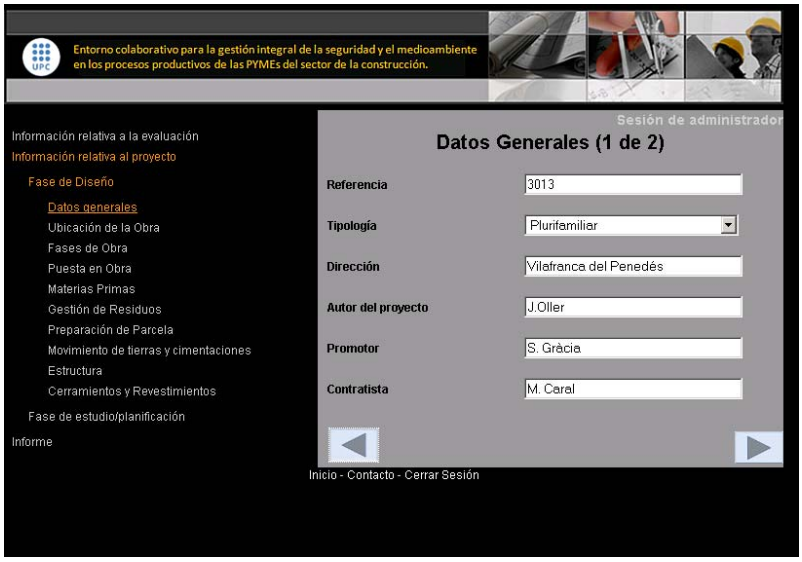

Fig. 11. Data-entry template: general information.

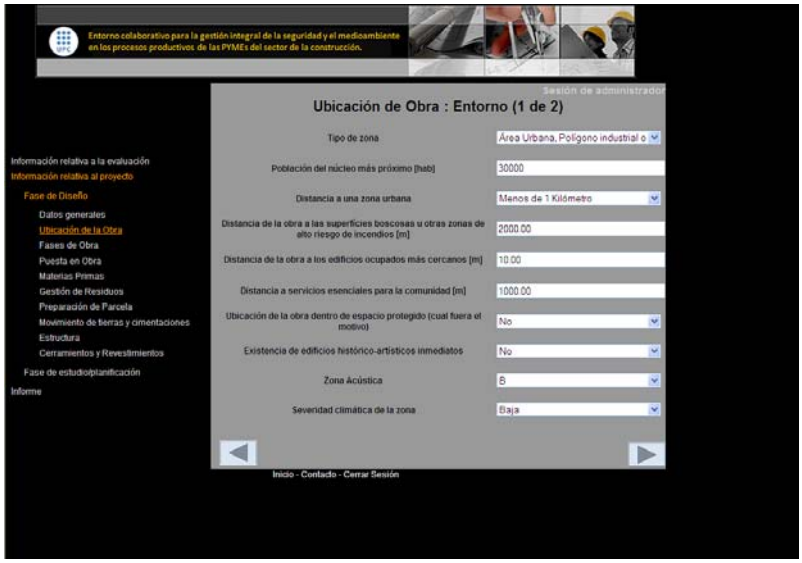

Fig. 12. Data-entry template: site location.

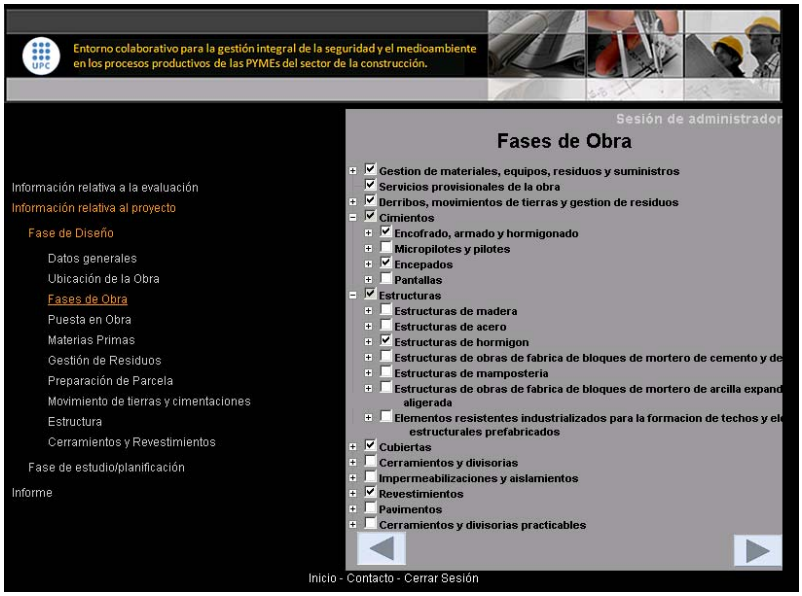

Fig. 13. Data-entry template: phase works.

Fig. 14. Data-entry template: raw materials consumption.

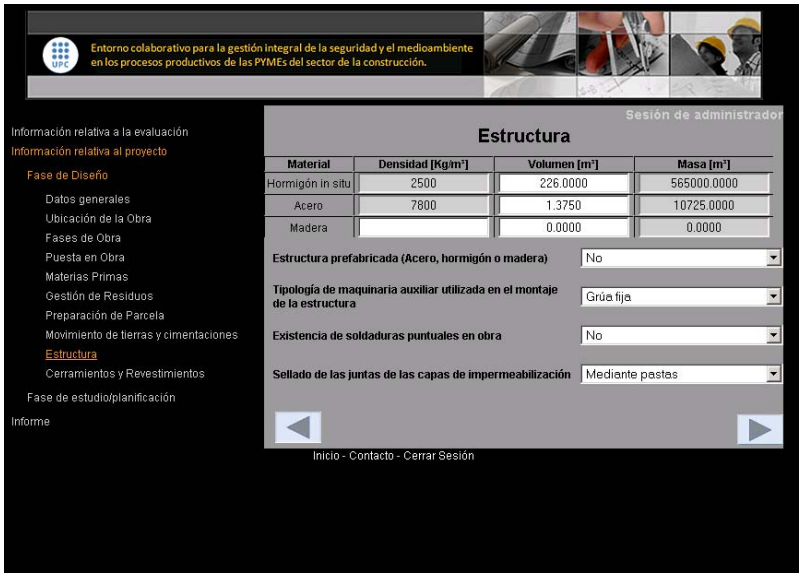

Fig. 15. Data-entry template: structure.

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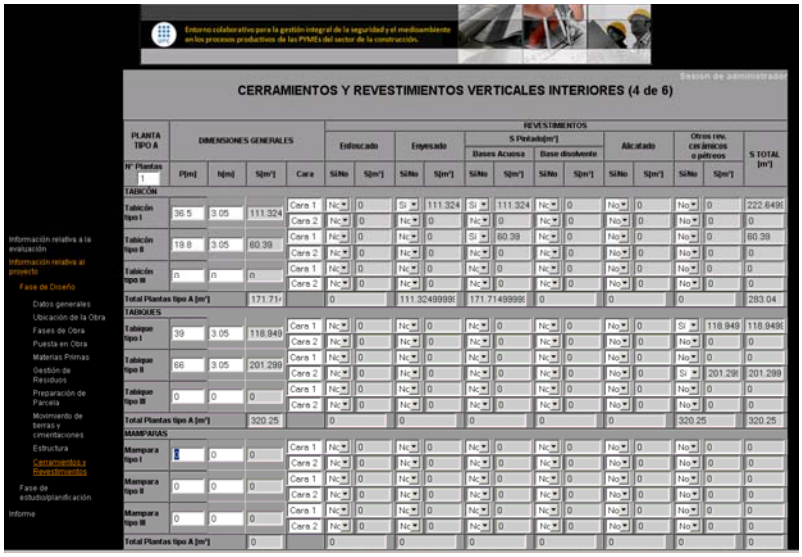


Fig. 16. Data-entry template: vertical closures and coatings.

4.5.2 Calculation

Upon completion of data entry via the templates, the system starts the calculation process. According to calculations stated in tables A.1, A.2 and A.3 to obtain the 68 performance indicators, a database determines which operations have to be done and how they must be carried out. Finally, performance indicators are contrasted with corresponding scoring systems.

4.5.3 Obtaining results

Finally, the web-based system displays the obtained results corresponding to the last assessment iteration (Fig. 17). Those environmental impacts or health and safety risks exceeding the pre-defined level of acceptability are highlighted in red. Significant environmental impacts and health and safety risks are linked to the ontology-based approach for on-site integrated environmental and health and safety management, which has been implemented through a radial browser (see chapter 5). In this way, the system can provide practical advice to diagnosed poor performance areas.

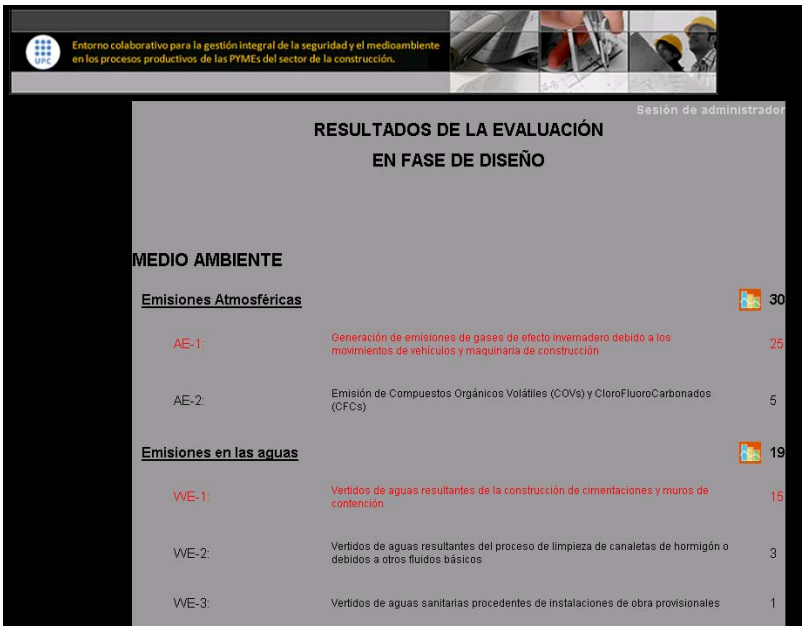


Fig. 17. Interface of assessment results.

Key data is also transformed into graphics in order to allow the comparison of the environmental and the health and safety performance of different design or planning alternatives. The system also produces a summary report with the most important data or figures of a particular construction project assessment (Fig. 18).

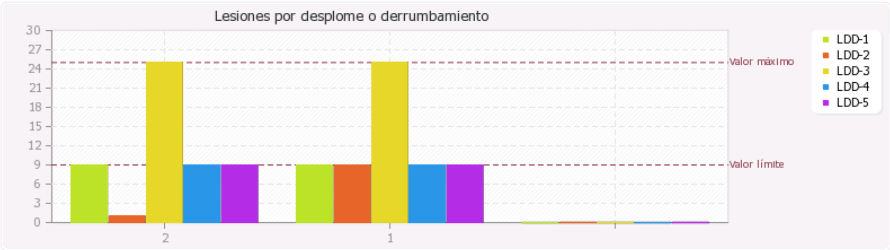


Fig. 18. Graphical presentation of the assessment results.

4.6 Conclusions

This chapter has detailed an innovative methodology for identifying and assessing environmental impacts and health and safety risks associated with the construction of new residential buildings by means of a process-oriented approach.

The proposed methodology serves as an assessment tool for measuring the safety and the environmental on-site performance of construction projects at the pre-construction stage (in the design, planning and preparation stages). The zero on the performance scale would represent the best performance within those environmental and health and safety areas deemed significant within the developed methodology. Higher scores would represent a construction project conforming to typical standards and practices in the region. Important increases from here on involve worse performance than typical. Apart from providing a comprehensive view of the environmental and health and safety on-site performance (understood as an overall picture), the methodology enables selective scrutiny of the various performance areas, as different aspects of the output could hold greater interest for different users. In this way, the methodology is able to rank the significance of the various environmental impacts and health and safety risks of each assessed project, so it allows comparing the performance score of one criterion with the score of other criteria within the same construction project.

The proposed methodology is able to compare the overall environmental impact and health and safety risk of various construction projects, so it allows the comparison of

the overall performance profile with that of other construction projects. The methodology is also able to compare the absolute importance of a particular environmental aspect or health and safety risk in various construction projects. In addition, for a specific performance criterion, the methodology allows assessing a performance criterion relative to a declared benchmark. Therefore, the methodology provides a consistent basis for comparisons, future labelling and environmental and safety benchmarking between different construction projects and construction companies.

In order to identify environmental aspects and health and safety risks related to the construction process, an exhaustive preliminary analysis with a process-oriented approach was carried out. As a result of this process, 30 significant environmental aspects and 84 significant health and safety risks for construction activities were obtained. The preliminary analysis with a process-oriented approach also allowed obtaining 7 risks that apply to both the environmental and the health and safety domains.

When assessing the magnitude of a particular environmental impact or the exposure to a particular health and safety risk, the developed methodology suggests a four-interval scale. In a similar way, when assessing the sensitivity of the receiving environment, a three-interval scale is suggested. Although more categories would obviously result on a better and more accurate outcome, they would also entail an increase on the complexity of the methodology. In order to help achieve a homogeneous outcome, numerical limits were established between these categories. Unfortunately, the literature provides no suitable models on which to base such a scoring system, so 0, 1, 3, 5 were established for impact magnitude (MG) and environment (EN) and 0, 1, 9, 25 were used for risk exposure (EX). However, alternative scoring systems could also be suitable for the intended purpose.

The assessment of the environmental impacts and health and safety risks related to the construction process involved the development of both direct and indirect indicators. Direct indicators were proposed whenever possible, since they are unequivocal. However, the developed methodology is intended to assess the significance of the environmental aspects and the health and safety risks derived from the building construction process in advance (prior to the construction stage) and this obviously makes difficult to find direct indicators. On the other hand, the developed methodology comprises mostly quantitative criteria. Quantitative criteria are widely used within the methodology and therefore the outcome of the process is as independent as possible of the people who conduct the assessment.

Although they have been traditionally controversial, building location and other contextual issues are included within the methodology through the environment

parameter. Its legitimacy for inclusion in a design tool is discussed because it is argued that in most cases building location and other contextual issues cannot be controlled by the designer (Cole, 1999). Taking into account that the relevance of each environmental impact or health and safety risk at a particular site is identified prior to the construction stage, significant environmental impacts and safety risks are highlighted in advance. Therefore, the inclusion of building location and other contextual issues in the methodology has been positively valued as they can highlight potential environmental impacts, which significance may be precisely derived from contextual issues. The early identification of these environmental impacts and health and safety risks enables designers to start a re-design process; otherwise, it is possible to assume a certain environmental impact or safety risk level during the construction of the project, as long as mitigating measures are going to be properly implemented on-site.

Qualitative criteria are used when assessing the environment parameter as in most cases quantitative data related to this parameter are not available within the construction project documents. Although criteria expressed qualitatively are open to wider interpretation by evaluators and therefore the assignment of points can vary considerably depending on those making the assessment, greater care and precision has been given to the description of the assessment scales.

A threshold or quantitative criterion has been defined in order to establish the acceptability of a potential environmental impact or health and safety risk. If after conducting the assessment, the significance of any environmental impact or health and safety risk is found to be unacceptable, actions to eliminate or reduce that impact or risk must be taken: abandoning the project in part or in its entirety, starting a re-design process or providing a range of procedures for mitigating adverse environmental impacts or safety risks that can then be implemented during on-site construction activities.

The development of a formal quantitative method allows obtaining a total score for each construction project alternative. In this case, the overall performance score is obtained by a simple aggregation of all the points assigned to each environmental aspect and health and safety risk. Therefore, in this methodology all criteria are assumed to be of equal importance and there is no discerned weighting for environmental impacts and health and safety risks (all the weighting factors are 1). Although several authors argue that weighting is the heart of all assessment schemes since it dominates the overall performance score of the construction project being assessed, they also recognize that there is at present neither a consensus-based approach nor a satisfactory method to guide the assignment of weighting (Cole, 1998; Lee et al., 2002; Ding, 2008). The two critical issues within this debate are the basis for deriving weightings and the manner in which the weighting process affects

the interpretation of the aggregated result (Cole, 1999). On one hand, weighting coefficients should be derived to suit local conditions or to reflect prioritised policies, although it has to be taken into account that public sector's opinion will definitely differ from that of the private developer (Ding, 2008). On the other hand, and if weightings are not clearly stated, the interpretation of the aggregated result may be confusing. In addition, the weighting coefficients may need to be updated regularly which can be a time consuming activity (Ding, 2008).

This methodology represents a step forward for the implementation of fully integrated environmental and health and safety management systems in construction companies, beyond a merely combination of documentation. As this methodology establishes the necessary basis and criteria to identify and assess environmental impacts and health and safety risks related to the construction process, it contributes to diminish the existing level of uncertainty related to the implementation process of an IMS, specifically when integrating the elements corresponding to identification and evaluation of environmental impacts and health and safety risks. The integration of environmental and health and safety management systems is stressed in this methodology as some of the identified risks related to the construction process apply at the same time to both the environmental and the health and safety domains.

Apart from providing an effective way of integrating separate MSs for environmental and health and safety management in construction companies, the developed methodology can also play an important role when implementing an EMS especially in small and medium-sized construction enterprises. As stated in chapter 2 and according to Põder (2006) and Seiffert (2008), the complexity, the limited transparency and the low reproducibility of the existing environmental impacts' assessment processes serve as a common shortcoming when implementing and up-keeping an EMS. It is worth mentioning here that in addition to general implementation barriers that may affect all sectors, previous researchers suggest that the inherent peculiarities of the construction industry hamper even more the implementation of MSs in construction companies (Bhutto et al., 2004; Piñeiro and García, 2007), due to difficulties encountered during the identification and assessment of environmental aspects.

Obviously, the same reasoning could apply to the safety domain. Therefore, the developed methodology also contributes to the implementation of separate OHSMS in small and medium-sized construction companies.

In order to reduce the time devoted to the assessment of each construction project, the developed methodology was implemented through an information technology-supported program (https://gric.upc.es/integracio/). The strength of the web-based system is that it allows reducing the time between data input and results obtainment.

Other key features of the developed implementation tool include the removal of geographic barriers as the system access is through an internet domain address. The use of an ordinary web browser eliminates the need for high-specification hardware and specific software and it also allows exchanging information at high speed and at relatively low cost. The web-based implementation tool also reduces human errors as data calculation is performed by the computer. Obviously, the web-based system also enhances the integration of the environmental and health and safety management in construction projects as a single interface allows assessing the project performance in both domains.

Chapter 5

Development of an ontology-based approach for on-site integrated environmental and health and safety management

5.1 Introduction

The primary aim of this dissertation is to develop a process-oriented methodology to enhance the integration of environmental and health and safety management systems for construction companies focusing on the sub-systems for identifying, assessing and operationally controlling environmental aspects and health and safety hazards using risk as an integrating factor. Chapter 4 has illustrated how quantitative methods can be applied to identify and assess the environmental impacts and health and safety risks associated with the construction of new residential buildings during the pre-construction stage. However, this dissertation also seeks to provide an effective way of integrating currently separate MSs for environmental and health and safety management in construction companies, contributing to reduce and, if possible, eliminate those obstacles related to a lack of understanding of how best to integrate the different MSs during risk control.

Therefore, this chapter explores an innovative approach to promote the implementation of IMSs in construction companies through integrated operational control. This chapter first provides a brief introduction to on-site operational control according to both ISO 14001:2004 and OHSAS 18001:2007. After providing a brief introduction to ontologies, chapter 5 proposes a guidance tool for effective on-site integrated environmental and health and safety management, using an ontology-based approach as a technical solution.

5.2 Operational control

Chapter 3 has argued that most common obstacles encountered by construction organizations during the implementation process of an IMS relate to a lack of understanding of how to integrate not only the elements for identifying and assessing risks but also for implementing necessary control measures (see figure 19).

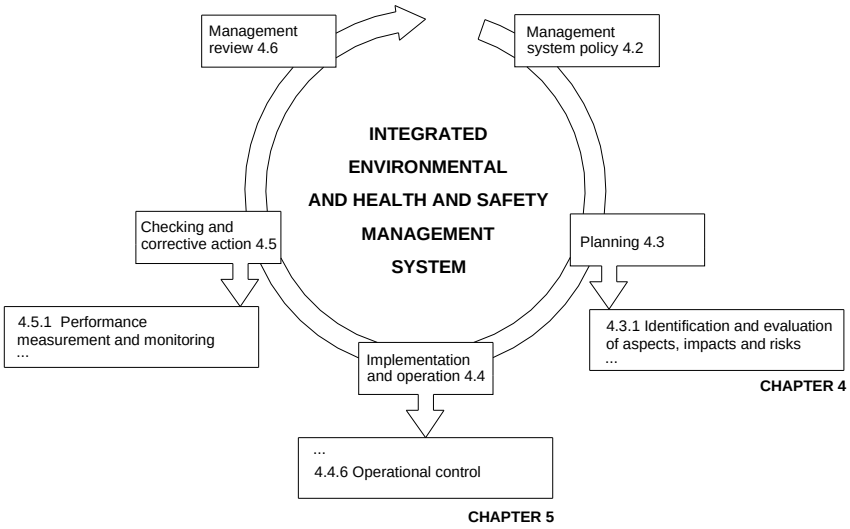


Fig. 19. General requirements for an integrated environmental and health and safety management system and outline structure of the thesis. Source: Adapted from OHSAS 18001:2007 and ISO 90001:2008.

Chapter 4 has developed a methodology to identify and assess the environmental impacts and health and safety risks related to the construction process in an

integrated way (corresponding to subsection 4.3.1 in table 1 and figure 19). This chapter focuses on improving the operational control of integrated environmental and health and safety management systems (corresponding to subsection 4.4.6 in table 1 and 4.4.1 in figure 19).

5.2.1 Operational control in ISO 14001 and OHSAS 18001

Operational controls are the various ways by which an organization can prevent pollution or accidents from its processes and activities. Operational controls usually include physical controls using electronic or mechanical technology to reduce emissions or accidents, routine preventive maintenance programs to reduce wear and breakdown of equipment and monitoring and observation of equipment performance and pollutant or safety levels. The choice of specific control methods depends on a number of factors, such as the complexity and environmental or health and safety significance of the operation itself and the skills and experience of people carrying out the operation. Most construction organizations implement operation controls through documented operating procedures and work instructions.

Referring to operational control, both ISO 14001:2004 and OHSAS 18001:2007 explicitly state that those processes and activities that can have a significant environmental impact or a significant health and safety risk and that are relevant to the organization's policies, objectives and targets need to be identified. Both standards also state that the organization shall plan its activities, including maintenance, in order to ensure that they are carried out under specified conditions by (1) establishing and maintaining documented procedures where their absence could lead to deviations from the policy, objectives and targets and (2) stipulating operating criteria in the procedures, among others. According to both ISO 14001:2004 and OHSAS 18001:2007, a procedure is a specified way of carrying out an activity or a process. Procedures should be documented when an activity is complicated, done infrequently, done by different people at different times or has sensitive operating variables. A documented procedure should clearly specify responsibilities, authority, resources, operating conditions, limits, targets, and precautions to consistently perform an activity. Documented procedures are also useful when training new operators.

On the other hand, both ISO 14001:2004 and OHSAS 18001:2007 require carrying out monitoring and measurement in order to determine the extent to which applicable requirements are being met (corresponding to subsection 4.5.1 in table 1 and figure 19). This shall include the recording of information to track performance of relevant operational control and to evaluate conformance with the organization's objectives and the ability of the processes to achieve planned results. In this sense, real performance data is clearly of significance if the primary objective is to

demonstrate continual improvement. However, monitoring and measurement is out of the scope of this research.

5.2.2 Integrated operational control

As argued in previous chapters, ISO 14001:2004 and OHSAS 18001:2007 are similar on the core issues as both are risk prevention oriented. Research results described in chapter 3 demonstrate that some of the risks related to the construction process apply to both the environmental and the health and safety domains (Fig. 6). In the same way, those documents describing the work process concerning each construction operation (documented procedures) may also apply to both the environmental and the health and safety domains. Therefore, documented procedures may also be managed in an integrated way. Reduction in procedures' duplication by combining the two systems has the potential to significantly reduce the overall size of the resulting MS and more importantly, to improve system efficiency and effectiveness.

A practical example of benefits from integration could be a procedure for welding, where the environmental requirements are described together with what kind of health and safety rules and equipment the employee has to apply. In the same way, noise or dust emissions on a construction site are hazards that should be reduced in order to address the health and safety of the construction workers, but this effort will also provide an environment improvement.

Undoubtedly, the integrated operational control can also highlight trade-offs between a single domain. Any on-site instruction focused on water saving by reusing rainwater will obviously reduce the environmental impact 'water consumption during the construction process' but it may also simultaneously worse the environmental impact 'land occupancy by the building, provisional on-site facilities and storage areas'. Moving to the health and safety domain, on-site work instructions for using ear protection headphones will clearly mitigate those safety risks related the generation of noise and vibrations due to site activities (contact with physical agents) but it may entail bad consequences in those safety risks related to any kind of falls as headphones may prevent hearing acoustic advices from construction vehicles and machinery.

The integrated operational control can also underline potential conflicts between the environmental and the health and safety domains. For example, an on-site instruction including provisional masonry closures to prevent falls between different levels clearly affects in a negatively manner the environmental impact 'raw materials consumption during the construction process'. In a same way, any work instruction related to selective waste management will have positive consequences

for the minimisation of any environmental impact included within the environmental category of waste generation but it may also affect in a negatively manner those safety risks related to injuries from being hit or run over by vehicles.

As argued in the previous subsection, both ISO 14001:2004 and OHSAS 18001:2007 require first identifying key operations and activities that are associated to identified environmental impacts and health and safety risks. Both norms also require implementing documented procedures and work instructions to ensure that activities are carried out under specified conditions. Considering environmental impacts and health and safety risks as central features within the operation control domain, construction processes represent their link back to its origins whereas work instructions represent the link to action. Therefore, four key concepts (environmental impacts, health and safety risks, construction processes and work instructions) and corresponding relationships configure the basis for an efficient on-site integrated operational control. In this context, the development of an ontology-based approach was considered to be suitable as ontologies have traditionally helped to represent key concepts and their relationships for a particular subject area in an effective manner.

Therefore and also motivated by the successful applications of ontology within other fields, the following subsection develops an ontology-based risk management framework for contractors to effectively integrate environmental and health and safety management systems, focusing on the existing interrelations –synergies as well as trade-offs –between the environmental and the safety domains.

5.3 Ontologies

This subsection briefly introduces the reader to the concept of ontology given that a complete discussion on this concept is considered to be out of the scope of this dissertation.

Although there is no universally agreed definition of ontology, one that is frequently cited is that given by Gruber (1993), who defined ontology as ‘an explicit specification of a conceptualization’. According to Darlington and Culley (2008), the definition provided by Knowledge Systems Laboratory (KSL) at the University of Stanford helps develop an understanding of what an ontology consists:

> ‘... it is a formal and declarative representation which includes the vocabulary (or names) for referring to the terms in that subject area and the logical statements that describe what the terms are, how they are related to each other, and how they can or cannot be related to each other. Ontologies therefore provide a vocabulary for representing and communicating

knowledge about some topic and a set of relationships that hold among the terms in that vocabulary.'

Ontologies are useful because they bring structure to the knowledge about a subject area and make it explicit (Darlington and Culley, 2008). Therefore, ontologies become a basis for knowledge management, effective communication, knowledge sharing and problem solving.

It is often highlighted by the experts that there is no correct way to model a domain. The best solution almost always depends on the application the ontology developer has in mind and the anticipated extensions (Noy and McGuiness, 2001). Therefore, the content of ontologies differs depending on the needs of the originator (Darlington and Culley, 2008).

5.4 Development of an ontology-based approach

5.4.1 Methodology used

Although it has been widely recognized that there is no single correct methodology for developing ontologies, this dissertation adopted the methodology provided by Noy and McGuiness (2001) to develop the ontology-based approach for on-site integrated environmental and health and safety management as it has been considered the clearest and most accessible methodology by domain specialists who have little or no prior knowledge of ontologies (Darlington and Culley, 2008). Figure 20 illustrates the main steps of the methodology provided by Noy and McGuiness (2001):

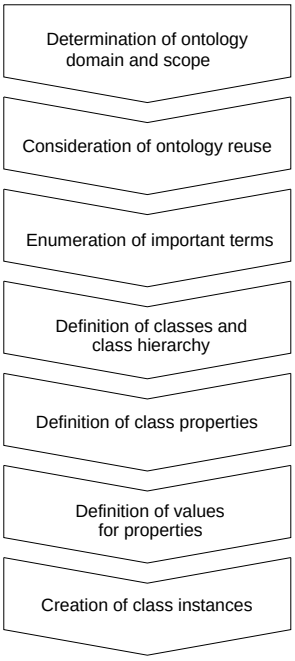


Fig. 20. Methodology for ontology development.
Source: Partially adapted from Noy and McGuiness (2001).

5.4.1.1 Determining the domain and scope of the ontology

According to Noy and McGuiness (2001), establishing the domain and scope of the ontology can be assisted by answering the following questions:

- What domain of interest will the ontology cover?
  The domain of interest is constituted of the concepts concerned with the integrated operational control of on-site environmental impacts and health and safety risks within the framework of ISO 14001:2004 and OHSAS 18001:2007.

- For what will the ontology be used?
  The purpose of the ontology-based approach for on-site integrated environmental and health and safety management is to provide a context of knowledge which can assist in raising and answering all the appropriate

questions to establish a well-defined framework for integrated on-site environmental impacts and health and safety hazards control.

- Who will use and maintain the ontology?
  The ontology-based approach for on-site integrated environmental and health and safety management will be used as guidance tool for contractors to effectively manage on-site environmental impacts and health and safety risks highlighted by the methodology developed in chapter 4 during the pre-construction stage. Therefore, the ontology-based approach, properly implemented in a web-based system (see subsection 5.4.3), will be used during the construction works by site managers, health and safety officers and environmental officers. On the other hand, the ontology-based approach will be maintained by the ontology manager, who can be a stakeholder of the project holding the responsibility of improving the hierarchical structure if necessary.

According to Noy and McGuiness (2001), one of the ways to determine the scope of the ontology is to sketch a list of questions that the ontology should be able to answer. The ontology-based approach for on-site integrated environmental and health and safety management should provide information about the following competency questions:

1) What are the environmental impacts typically related to the construction process of a residential building?

2) What are the health and safety risks typically related to the construction process of a residential building?

3) What construction processes may cause a particular environmental impact or health and safety risk?

4) What are the environmental impacts and the health and safety risks related to a particular construction process?

5) Which risks apply to both the environmental and the safety domains?

6) What work instructions should be implemented during on-site construction activities to lower the significance of a particular environmental impact or of a health and safety risk in a specific construction project?

7) What implemented work instructions may be tangentially beneficial for a particular environmental impact or health and safety impact?

8) What implemented work instructions may be detrimental for a particular environmental impact or health and safety impact?

Competency questions are considered to be important in focusing on what the ontology is to be used for, and providing guidance as to the structure and content of the ontology (Noy and McGuiness, 2001). However, they also provide a means by which the ontology, and its implementation in some problem-solving method, can be validated (see subsection 5.4.3), since they can be used to query an application's performance (Darlington and Culley, 2008).

5.4.1.2 Considering reuse of existing ontologies

Taking into account that the development of ontologies is motivated by, amongst other things, the idea of knowledge reuse and shareability (Darlington and Culley, 2008), several ontology libraries were accessed. Unfortunately, neither the Ontolingua library (KSL, 2008), which is a component of the Ontolingua Server, nor the DAML library (DAML, 2008) included reusable ontologies within the on-site environmental and health and safety management domain. Several research projects within the construction field, such as LexiCon, eConstruct and eCognos projects, were also reviewed but they did not include useful ontologies for the abovementioned purpose. Construction research initiatives on ontology development are mainly focused on the standardization of knowledge representation. In this sense, it is worthwhile to highlight recent developments in construction industry standards such as the ISO 12006 (organization of information about construction works, part 2: framework for classification of information and part 3: framework for object-oriented information), the Unified Classification for the Construction Industry (Uniclass) and the Industry Foundation Class (IFC).

Ontologies have been mostly applied to support information and knowledge management systems within the construction industry. In this sense, Anumba et al. (2002) developed an ontology to support the communication of domain agents in the collaborative design of industrial buildings. El-Diraby et al. (2005) proposed a domain taxonomy for construction concepts as a key step towards the development of a formal ontology for construction knowledge within the framework of the e-COGNOS project. Anumba et al. (2008a) presented an ontology-based approach to project information management in a semantic web environment. Issa and Mutis (2006) proposed an ontology based framework using a semantic web for addressing semantic reconciliation in construction. The above catalogue of ontology-related research papers is not comprehensive but it may be completed consulting the work of Anumba et al. (2008b), who presented a detailed exploration of other ontology-based approaches to information and knowledge management in construction.

In some other cases, the ontology is not just dedicated to modelling the concepts and interrelationships of a particular subdomain but also supports other applications. This is the case of Staub-French et al. (2003), which developed an ontology of features to support cost calculations. Edum-Fotwe and Price (2009) put forward an ontology that provided a systematic articulation of the social dimension of sustainability for evaluating the viability of projects in the construction sector.

In some other papers, ontologies support decision-making during the design process. In this sense, Garcia et al. (2004) developed an ontology to support the design process in construction projects complementing virtual design and extreme collaboration. Pandit and Zhu (2007) developed an ontology to support the evaluation of design alternatives of Engineer-To-Order products. Ugwu et al. (2005) proposed an ontology-driven solution that addresses constructability during the decision-making process related to the design of steel frame structures. An ontology was also created for use in designing steel skeletal structures by Skolick and Kicinger (2002).

As this dissertation focuses on on-site environmental and health and safety management, no existing ontologies were found to be useful. In this sense, Darlington and Culley (2008) argue that currently, the number of existing and available formally represented ontologies is minimal when compared with the subject matter potentially available for formalization (the entire conceptual world). They also state that it is not surprising then, when looking for a suitable ontology, to find that no ontology exists which relates to the current area of formalisation (Darlington and Culley, 2008), or that an ontology does exist, but the viewpoint from which it was constructed disqualifies its use (Benjamin et al., 1996; Darlington and Culley, 2008).

5.4.1.3 Enumerating important terms

This step constitutes the starting-point for building a new ontology and according to Darlington and Culley (2008) consists of the two tasks of (a) identification of the key concepts and relationships in the domain of interest and (b) production of unambiguous text definitions for such concepts and relationships.

Requirements stated in ISO 14001:2004 and OHSAS 18001:2007 under the subsection of operational control were the basis for developing the ontology to enhance integrated on-site environmental and health and safety management. The first requirement of ISO 14001:2004 and OHSAS 18001:2007 refers to the identification of key operations and activities that are associated with identified environmental impacts and hazards. The second requirement explicitly refers to the implementation of documented operating procedures to cover situations where the

absence of a procedure could lead to deviations from the policy, objectives and targets. Generally, operating procedures prescribe how specific tasks are to be performed whereas work instructions provide specific details (step-by-step instructions) about the required work. Thus, work instructions are the product of implementing procedures.

Therefore, environmental impacts, health and safety risks, construction processes (key operations and activities that are associated to identified environmental aspects and hazards), and work instructions (operating procedures covering situations where its absence could lead to deviations) are identified as being crucial for integrated operational control:

- Environmental impacts
  According to ISO 14001:2004, environmental impacts are defined as any changes to the environment, whether adverse or beneficial, wholly or partially resulting from an organisation's activity, product or service.

- Health and safety risks
  According to OHSAS 18001:2007, risk is defined as the combination of the likelihood of an occurrence of a hazardous event or exposure(s) and the severity of injury or ill health that can be caused by the event or exposure(s).

- Construction processes
  A process is defined by the Project Management Institute (2009) as a set of interrelated actions and activities performed to achieve a specified set of products, results, or services. Therefore, construction processes may be defined in this dissertation as a set of interrelated actions and activities performed to achieve a construction entity, in this case, a residential building.

- Work instructions
  According to both ISO 14001:2004 and OHSAS 18001:2007, a procedure is defined as a specified way to carry out an activity or a process. Procedures contain the basic process for performing a function at operational level and therefore, they are often supported by detailed work instructions, which contain the exact process for performing the function.

The above conceptual structure represents a starting point in identifying the areas of interest that may now be mapped ontologically when attempting to support integrated on-site environmental and health and safety management. Considering environmental impacts and health and safety risks as central features within this

domain, construction processes represent their link back to their origin whereas work instructions represent the link to action.

5.4.1.4 Defining the classes and the class hierarchy

According to Noy and McGuiness (2001), classes describe concepts that have independent existence in the domain. Therefore, major classes in the ontology-based approach for on-site integrated environmental and health and safety management correspond to the key concepts identified in the previous step: environmental impacts, health and safety risks, construction processes, and work instructions.

It has been widely argued by previous researchers that it is always worth considering the reuse of existing controlled vocabularies (ontologies, taxonomies or thesaurus). For this reason, an exhaustive search within several controlled vocabularies focusing on the construction domain was carried out. Lima et al. (2007) provides a non-comprehensive list of well-known efforts in this area, which includes ISO 12006 part 2: framework for classification of information, Lexicon (Stabu, the Netherlands), BARBi-Building and construction reference data library (Norwegian Building Research Institute), bcBuildingDefinitions taxonomy (e-Construct Project), ICONDA terminology (Franhofer IRB), BS6100 and UNICLASS (British Standards), e-Cognos ontology (e-Cognos project) and Standard Dictionary for Construction (Gencod EAN, France). Other initiatives include Industry Foundation Classes (International Alliance of Interoperability), Canadian Thesaurus of Construction Science and Technology (National Research Council, Canada), Construction Management Standards of Practice (Construction Management Association of America), MACE Taxonomy (Metadata Architectural Contents in Europe-MACE project), Content Thesaurus on subterranean works (La Ciudad Multidimensional research project). Unfortunately, the main handicap of all these semantic resources lies in the fact that they do not include on-site environmental and health and safety management related terms or they are not concise enough.

On the other hand, other controlled vocabularies within the environmental or the health and safety domains are not focused enough on the construction sector. In some specific cases, controlled vocabularies are related to construction safety, but they are not wide enough so as to cover health and safety risks related to the construction process and on-site safety work instructions. In the same way, some semantic resources focus on sustainable construction but they do not cover environmental impacts related to the construction process and on-site environmental work instructions.

Since no existing semantic resources were found to be suitable according to the primary aim of the ontology-based approach for on-site integrated environmental

and health and safety management, classes and class hierarchy were defined for the major classes: construction processes, environmental impacts, health and safety risks and work instructions. According to Noy and McGuiness (2001), three approaches to the development of the class hierarchy are typically distinguished: top-down, middle-out and bottom-up. A top-down development process starts with the definition of the most general concepts in the domain and the subsequent specialization of the concepts. A bottom-top development process starts with the definition of the most specific classes, with subsequent grouping of these classes into more general concepts. A middle-out development process is a combination of the top-down and bottom-up approaches: the more salient concepts are defined first and then generalized and specialized appropriately. According to Noy and McGuiness (2001), none of these three methods is inherently better than any of the others.

Therefore, each major class will have related subclasses and even sub-subclasses. A subclass of a class represents a concept that is 'a kind of' the concept the superclass represents. In any case, and in order to ensure the correct definition of subclasses and sub-subclasses, all the subclasses of a class were checked to have a relation 'is a' with their class.

a) Construction Processes

In order to propose a feasible ontology-based approach, this dissertation adopted as construction processes those work sections provided by the Catalan Institute of Construction Technology within the MetaBase database (ITeC, 2006). Two main reasons support this decision:

- Environmental impacts and health and safety risks related to the construction process were obtained by means of a process-oriented approach (see section 4.3). In both cases, construction stages and activities taken into consideration were those work sections provided by ITeC within the MetaBase database.

- The MetaBase database, which includes reference prices for work sections, is the most widely used information source by official and private entities (designers and contractors) in Catalonia since 1985.

Figure 21 and subsection C1 illustrate a total of 286 classes, subclasses and sub-subclasses related to the major class 'Construction processes'.

b) Environmental Impacts

In this case, classes and class hierarchy were identified by means of a process-oriented approach, using the construction processes provided by the MetaBase database (ITeC, 2006) and the generic environmental aspects provided by the Eco-Management and Audit Scheme (EMAS). Therefore, in this case, a top-down approach was used since environmental impacts related to the construction process were obtained from standardized generic environmental impacts. This approach, which is described in section 4.3 of this dissertation, made it able to obtain the classes and class hierarchy within the major class 'Environmental Impacts' (Fig. 22 and subsection C2). In this case, 46 classes, subclasses and sub-subclasses were considered within the major class of 'Environmental Impacts'.

c) Health and Safety Risks

Health and safety risks related to the construction process were also obtained by means of a process-oriented approach, using the construction processes provided by ITeC and the generic health and safety risks provided by the Occupational Accident Report Form of the Spanish National Institute of Safety and Hygiene at Work (see section 4.3). Therefore, in this case, a top-down approach was also used to identify the classes and class hierarchy related to the major class 'Health and Safety Risks' (Fig. 23 and subsection C3). Finally, a set of 116 classes, sub-classes and sub-subclasses were obtained within the major class 'Health and Safety Risks'.

d) Work Instructions

Previous studies adopted a variety of methods to extract important concepts from the target domain including a review of existing taxonomies, a review of the literature, an analysis of a sample document, etc. (Tserng et al., 2009). Since no controlled vocabularies covering on-site work instructions were found to be previously developed within the existing literature, this research adopted sample document analysis as the major concept extraction method.

The knowledge database for concept extraction was based on the on-site environmental instructions developed under the European research project RECONS - Reducing environmental construction impact (LIFE03 ENV/E/000150) (Gremi de Constructors d'Obres de Barcelona i Comarques, 2007) and the on-site safety work instructions published by the Government of Catalonia (Construccions Rubau et al., 2007). Given that in both cases on-site work instructions were developed by a panel of experts, it can be assumed that they were comprehensive and rigorous enough so as to configure the right knowledge database for concept extraction.

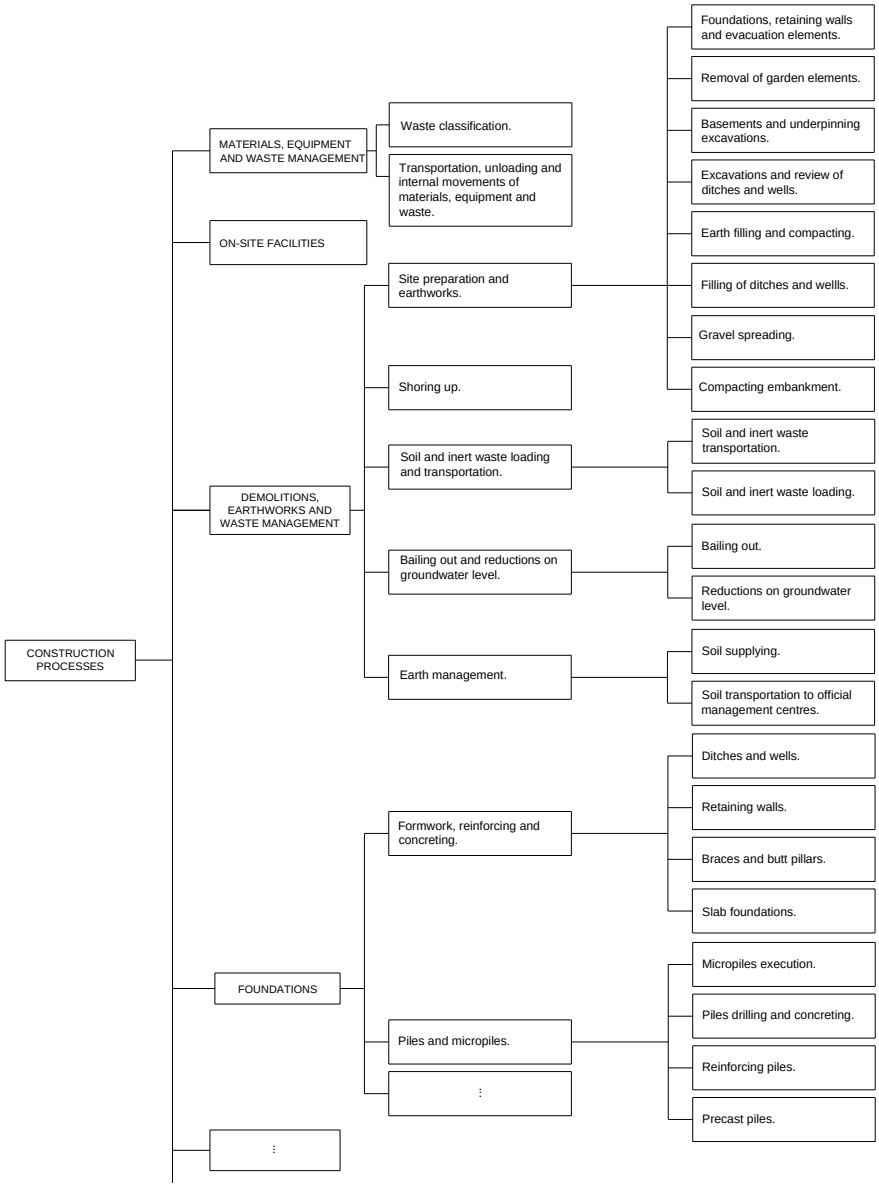


Fig. 21. Classes and class hierarchy for 'Construction Processes'.
Source: Partially adapted from MetaBase by ITeC.

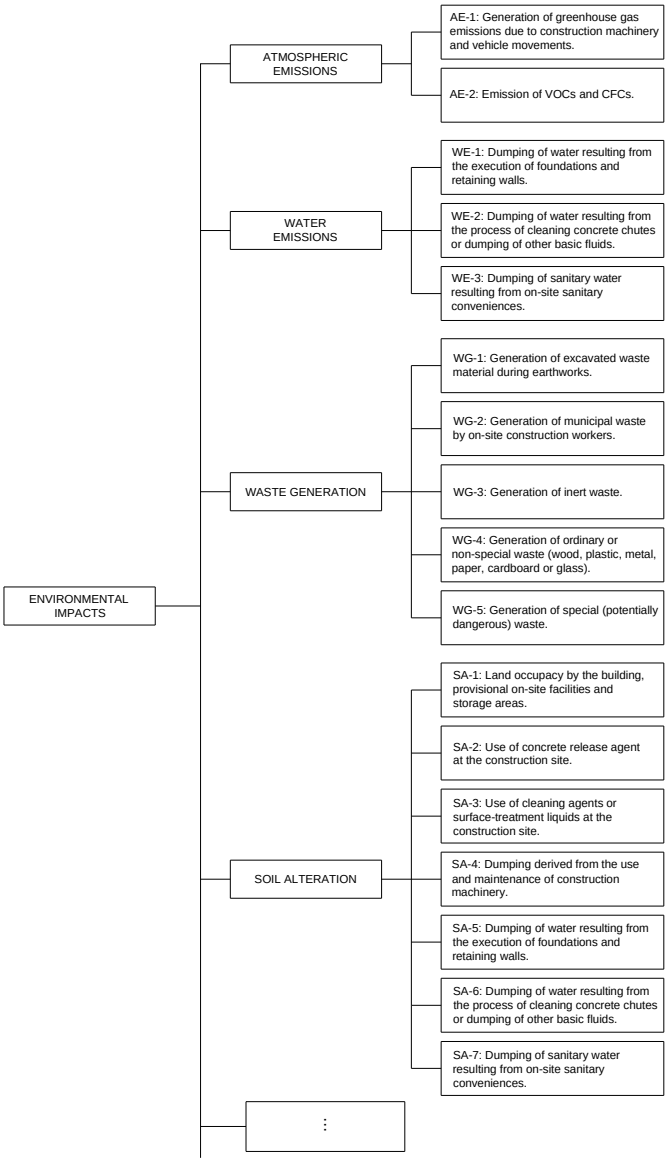


Fig. 22. Classes and class hierarchy for 'Environmental Impacts'.

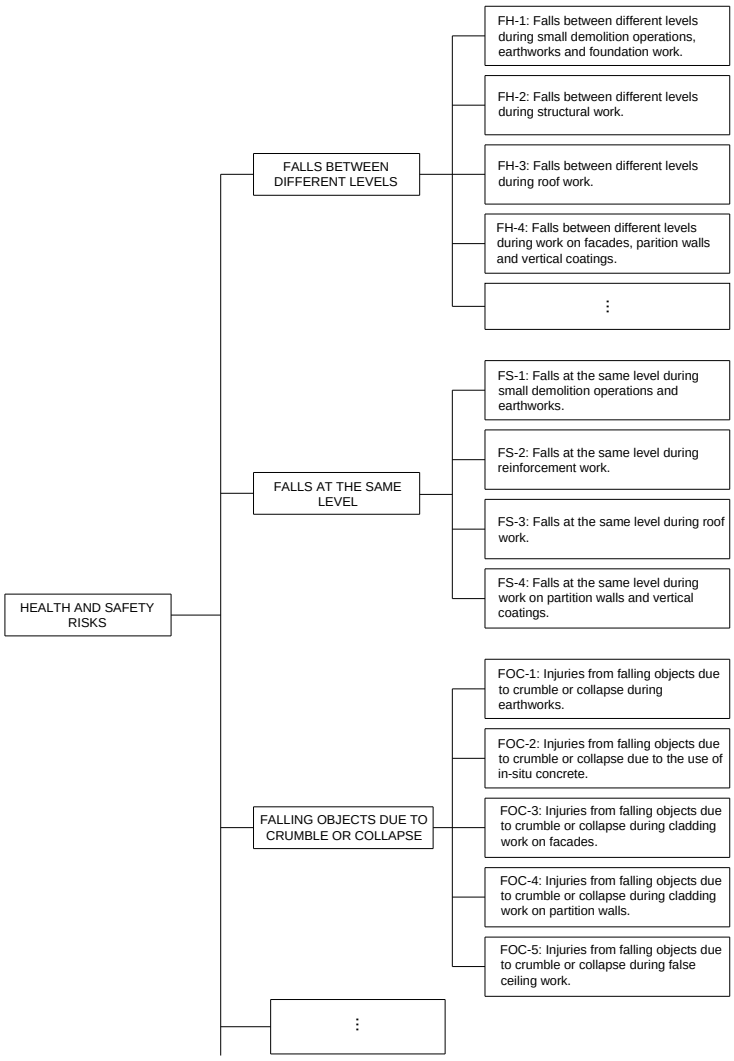


Fig. 23. Classes and class hierarchy for 'Health and Safety Risks'.

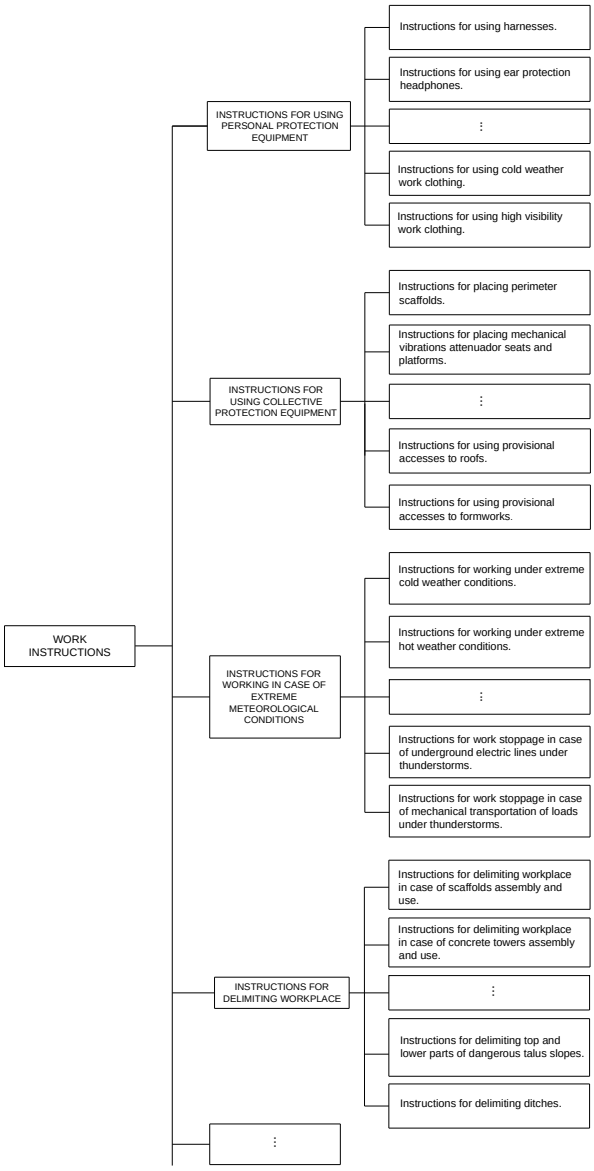


Fig. 24. Classes and class hierarchy for 'Work Instructions'.

Selected reference documents were thoroughly analysed in order to identify words with a relevant meaning within the domain. Through this extraction method, concepts were reformulated iteratively. This involved decomposing some concepts into simpler ones, creating new ones, clustering together any set of related concepts, and combining some concepts that are synonymous into a single concept. Finally, a set of approximately 300 concepts emerged (Fig. 24 and subsection C4).

5.4.1.5 Defining the properties of classes

According to Noy and McGuiness (2001), classes on their own do not provide enough information to answer the competency questions defined in the first step. Once the classes have been defined, the structure of the concepts must be described. Therefore, this step was focused on generating a set of relationships that showed a structural representation of the identified concepts.

Figure 25 illustrates the conceptual structure defining the interactions between the various concepts in the problem domain:

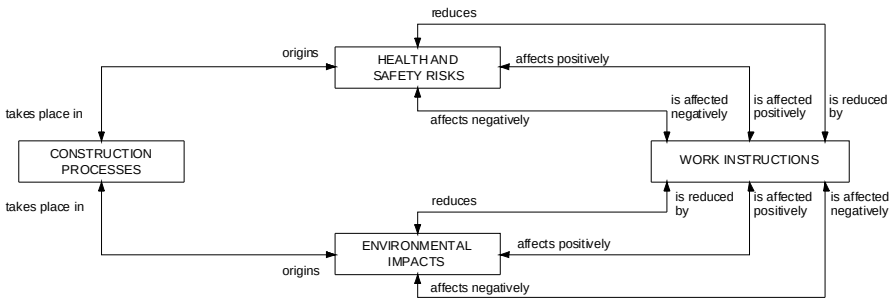


Fig. 25. Conceptual structure showing the relationships between major classes in the ontology-based approach for on-site integrated environmental and health and safety management.

Object properties link an individual to an individual:

- The relationship 'takes place in' relates 'Health and Safety Risks' and 'Environmental Impacts' to corresponding 'Construction Processes'. Each health and safety risk takes place during one or more construction processes. In a similar way, each environmental impact also takes place during one or more construction processes.

- The relationship ‘origins’ is the inverse relation of ‘takes place in’. Each construction process causes one or more environmental impacts. In a similar way, each construction process also causes one or more health and safety risks.

- The relationship ‘reduces’ relates ‘Work Instructions’ to corresponding ‘Health and Safety Risks’ and ‘Environmental Impacts’. Each work instruction may reduce one or more health and safety risks. In a similar way, each work instruction may also reduce one or more environmental impacts.

- The relationship ‘is reduced by’ is the inverse of ‘reduces’. Each health and safety risk may be reduced by one or more work instructions. In a similar way, each environmental impact may also be reduced by one or more work instructions.

- The relationship ‘affects positively’ relates ‘Work Instructions’ to corresponding ‘Health and Safety Risks’ and ‘Environmental Impacts’. Each work instruction may positively affect one or more health and safety risks. In a similar way, each work instruction may also affect one or more environmental impacts positively.

- The relationship ‘is affected positively’ is the inverse of ‘affects positively’. Each health and safety risk may be affected by one or more work instructions positively. In a similar way, each environmental impact may also be affected by one or more work instructions positively.

- The relationship ‘affects negatively’ relates ‘Work Instructions’ to corresponding ‘Health and Safety Risks’ and ‘Environmental Impacts’. Each work instruction may affect one or more health and safety risks negatively. In a similar way, each work instruction may also affect one or more environmental impacts negatively.

- The relationship ‘is affected negatively’ is the inverse relation of ‘affects negatively’. Each health and safety risk may be affected by one or more work instructions negatively. In a similar way, each environmental impact may also be affected by one or more work instructions negatively.

A property is attached to the most general class that can have that property. All subclasses of a class inherit the property of that class. For example, all the properties of the class ‘Environmental Impacts’ will be inherited by all subclasses and sub-subclasses of ‘Environmental Impacts’, including ‘Atmospheric Emissions’ and

‘Generation of greenhouse gas emissions due to construction machinery and vehicle movements’.

Both the relationships ‘takes place in’ relating ‘Health and Safety Risks’ and ‘Environmental Impacts’ to corresponding ‘Construction Processes’ and its inverse relationship ‘origins’ were obtained by means of a process-oriented approach (section 4.3). Other relationships relating ‘Work Instructions’ to corresponding ‘Health and Safety Risks’ and ‘Environmental Impacts’ were specifically derived taking into account the purpose of the ontology-based approach for on-site integrated environmental and health and safety management.

Finally, more than 6,100 relationships were included within the ontology-based approach for on-site integrated environmental and health and safety management. Tables C.1, C.2 and C.3 detail the number of established relationships between ‘Environmental Impacts’, ‘Health and Safety Risks’, ‘Construction Processes’ and ‘Work Instructions’

In this context, neither datatype properties nor annotation properties needed to be defined.

5.4.1.6 Defining values for properties

Properties can have different facets describing the value type, allowed values, the number of the values (cardinality), and other features of the values the property can take (Noy and McGuiness, 2001). In this case, constraints on the value of properties did not need to be stated.

5.4.1.7 Creating instances of classes

According to Noy and McGuiness (2001), the last step is creating individual instances of classes in the hierarchy. Defining an individual instance of a class requires choosing a class, creating an individual instance of that class and filling in the specific property values.

In this case and according to the purpose of the developed ontology-based approach, no instances needed to be created. Instances should only be created in the case of a particular construction company using the developed ontology-based approach for on-site integrated environmental and health and safety management having its own procedures and on-site work instructions. In this case, a particular on-site work instruction already existing in the construction company could be an instance of the corresponding subclass or sub-subclass of the ontology. Creating instances of classes allows the semantically matching of work instructions already existing in

any construction company to the developed classes and subclasses, allowing the universalization of the developed ontology.

5.4.2 Implementation of the ontology-based approach for on-site integrated environmental and health and safety management

The ontology-based approach for on-site integrated environmental and health and safety management was implemented through a radial browser developed by Moritz Stefaner (Stefaner, 2009). The code, licensed under a Creative Commons Attribution – Non Commercial – Share Alike License, allows displaying complex concept network structures in an intuitive manner. The application was originally created with Flash and it was edited with Macromedia Flash 8. Classes, subclasses, sub-subclasses and the object properties were stored in a XML file.

A complete visualization of the developed ontology-based approach can be seen at https://gric.upc.es/integracio/ (username: thesis; password: gangolells). Subsections 5.5 and 6.2.4.2 show some screenshots.

5.4.3 Validation of the ontology-based approach for on-site integrated environmental and health and safety management

This chapter has developed an ontology-based risk management framework to help contractors effectively manage on-site environmental impacts and health and safety risks, focusing on the existing interrelations (synergies as well as trade-offs) between the environmental and the safety domains. In order to get a proper visualization of the solution, the ontology-based approach for on-site integrated environmental and health and safety management has been implemented through a radial browser developed by Moritz Stefaner (Stefaner, 2009).

For the validation of the ontology-based approach, an internal evaluation was performed during its development. Verifications were done by checking whether the information was available in the ontology-based approach and if the right relationships existed. This fist validation activity was carried out by the developer of the ontology-based approach.

Secondly, and according to what is suggested by the existing literature, competency questions were used in order to validate the developed ontology-driven solution. Table 8 shows how the ontology-based approach for on-site integrated environmental and health and safety management is able to answer the competency

questions initially defined (section 5.4.1.1). Therefore, the conceptual structure can be considered reasonable and correct for its intended purpose.

COMPETENCY QUESTIONS	FIGURES ANSWERING COMPETENCY QUESTIONS
1) What are the environmental impacts typically related to the construction process of a residential building?	Figure 29 shows all the environmental categories within the environmental domain. Figure 27 shows the environmental impacts included within a particular environmental category.
2) What are the health and safety risks typically related to the construction process of a residential building?	Figure 30 shows all the health and safety categories within the safety domain. Figure 28 shows the health and safety risks included within a particular health and safety category.
3) What construction processes may cause a particular environmental impact or health and safety risk?	Figure 33 shows all the construction processes causing a particular environmental impact.
4) What are the environmental impacts and the health and safety risks related to a particular construction process?	Figure 34 shows all the environmental impacts (in green and blue) and health and safety risks (in red and blue) related to a particular construction process.
5) Which risks apply to both the environmental and the safety domains?	Figures 28 and 27 show (in blue) those risks applying to both the environmental and the health and safety domain.
6) What work instructions should be implemented during on-site construction activities to lower the significance of a particular environmental impact or of a health and safety risk in a specific construction project?	Figures 26 and 31 show (with a 'R' relationship) those work instructions that can lower the significance of a particular environmental impact.
7) What implemented work instructions may be tangentially beneficial for a particular environmental impact or health and safety impact?	Figures 26 and 31 show (with a '+' relationship) those work instructions that may be tangentially beneficial for a particular environmental impact.
8) What implemented work instructions may be detrimental for a particular environmental impact or health and safety impact?	Figures 26 and 31 show (with a '-' relationship) those work instructions that may be tangentially detrimental for a particular environmental impact.

Table 8. Figures answering the competency questions initially stated.

Thirdly, the implementation of the ontology-based approach through a radial browser was tested for correctness and accuracy. For this reason, the application was

tested under different conditions, facilitating finding and correcting errors. Lastly, the verification of the computerized ontology-based approach ensured that the computer programming and implementation of the developed solution was correct.

Finally, and once the ontology-based approach for on-site integrated environmental and health and safety management was correctly developed and implemented, an external evaluation performed by three domain experts, all of them PhD in construction engineering, was carried out.

In a first stage, and in order to assure ease of navigation, experts were asked to find four concepts in the developed application. Table 9 shows the time devoted by the experts to find four concepts (one environmental category, one environmental impact, one health and safety category and one health and safety risk) within the ontology-based approach. Based on the achieved results, it can be concluded that the developed ontology-based approach presents an acceptable ease of navigation.

EXPERT SURVEY	**EXPERT 1**	**EXPERT 2**	**EXPERT 3**
Electric contacts.	18 ”	15 ”	13 ”
FS-2 Falls at the same level during reinforcement work.	24 ”	26 ”	35 ”
Soil alteration.	10”	13 ”	17 ”
WG-3 Generation of inert waste.	21 ”	12”	16 ”

Table 9. Assessment of the ease of navigation.

Secondly, the experts were asked to check whether the ontology-based approach could answer the pre-defined competency questions. However, competency questions had to be customized in order to make the external evaluation easier. Table 10 shows the obtained results. According to the experts, the competency question ‘Which risks apply to both the environmental and the safety domains?’ was found to be the most difficult. In fact, the developed solution distinguishes those risks that apply to both the environmental and the safety domains because they are coloured in blue but they are not ease to find if you do not have previous related knowledge. In spite of this, results obtained during this validation activity allow concluding that the ontology-based approach is reasonable and correct for its intended purpose.

EXPERT SURVEY	EXPERT 1	EXPERT 2	EXPERT 3
1) What are the environmental impacts typically related to the construction process of a residential building?	✓	✓	✓
2) What are the health and safety risks typically related to the construction process of a residential building?	✓	✓	✓
3) What construction processes may cause the environmental impact 'T1 - Increase in external road traffic due to construction site transport'?	✓	✓	✓
4) What are the environmental impacts and the health and safety risks related to the construction process 'Demolitions, earthworks, and waste management: soil and inert waste transportation'?	✓	✓	✓
5) Which risks apply to both the environmental and the safety domains?	✗	✗	✓
6) What work instructions should be implemented during on-site construction activities to lower the significance of the safety risk 'FOH-3 Injuries from falling objects during handling in cladding work'?	✓	✓	✓
7) What implemented work instructions may be tangentially beneficial for the safety risk 'FOH-3 Injuries from falling objects during handling in cladding work'?	✓	✓	✓
8) What implemented work instructions may be detrimental for the safety risk 'FOH-3 Injuries from falling objects during handling in cladding work'?	✓	✓	✓

Table 10. Experts' answers to competency questions.

Thirdly, interviews with the domain experts were also performed in order to assure the applicability of the proposed ontology-based approach. Experts did not have major comments in this sense and general assessment about the developed ontology-based approach for on-site integrated environmental and health and safety management was positive (Table 10).

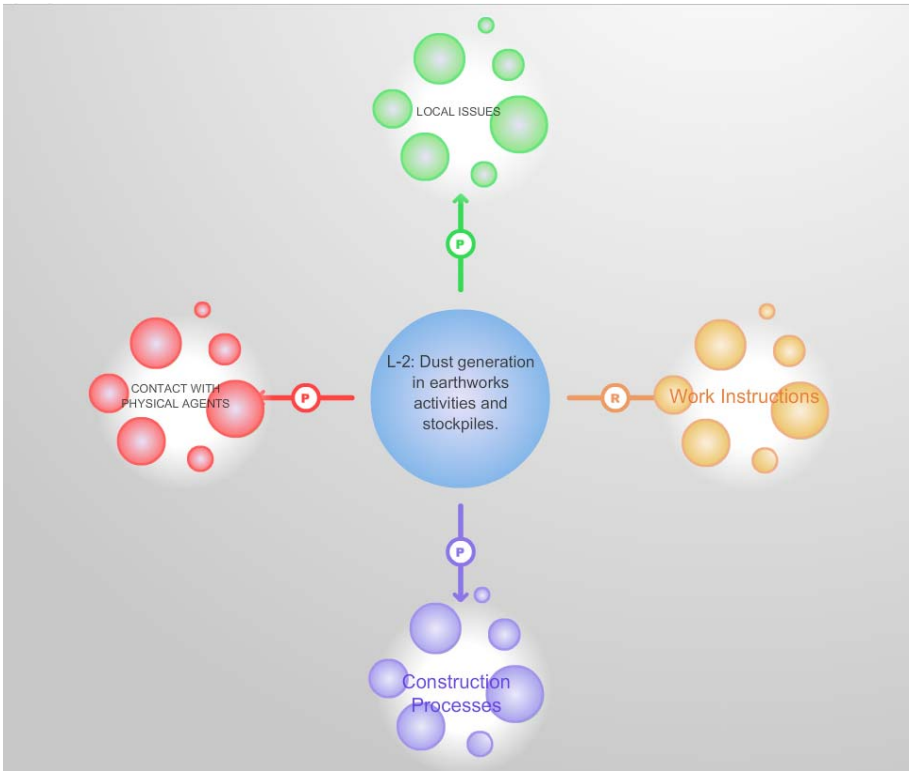
EXPERT 1	I think that the application is going to be useful for better on-site integrated management.
EXPERT 2	-
EXPERT 3	-

Table 11. Experts' comments on the developed ontology.

5.5 Operational control through the ontology-based approach for on-site integrated environmental and health and safety management

In order to reduce the negative effects of environmental impacts and health and safety risks, it is important to identify, as early as possible, their significance in a particular construction project (see chapter 4). Therefore, and once potential environmental impacts or health and safety risks are identified, corresponding on-site work instructions must be planned and implemented. At this moment, the ontology-based approach for on-site integrated environmental and health and safety management can be used as a framework by the construction company to proactively manage these impacts and risks.

For each environmental impact or health and safety risk highlighted as significant by the aforementioned methodology, the ontology-based approach for on-site integrated environmental and health and safety management shows which construction processes constitute its origin and which work instructions configure the link to action. In addition, the application also shows the corresponding category (or superclass) to which the environmental impact or health and safety risk belongs (Fig. 26).

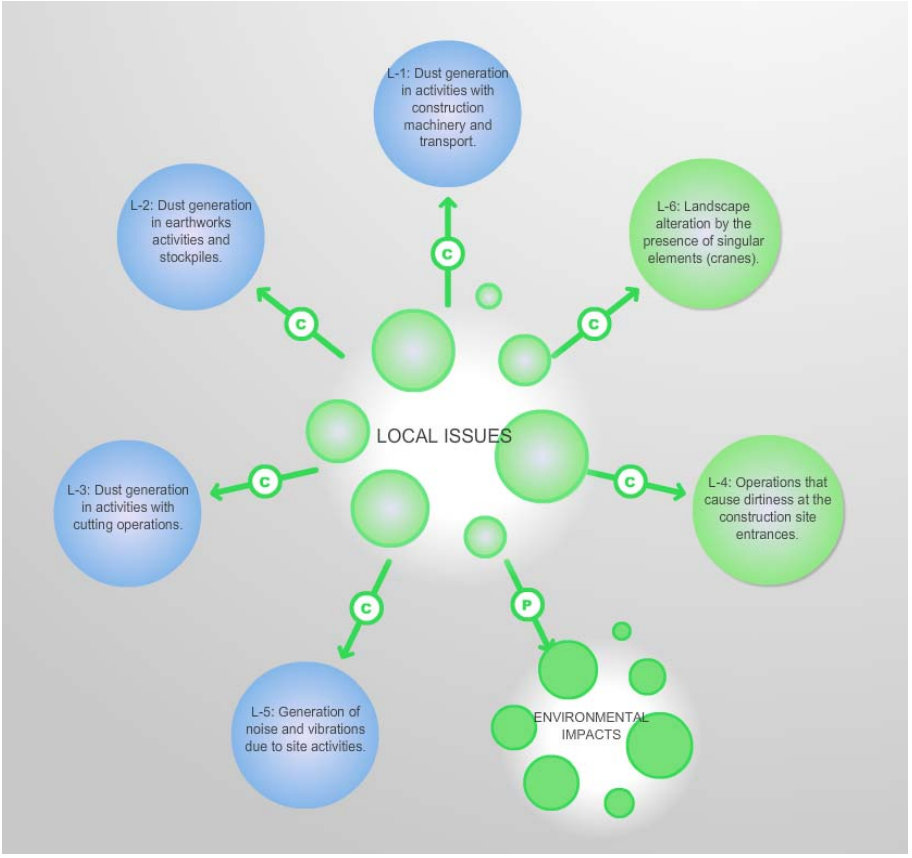


The 'P' relationship indicates that the environmental impact / health and safety risk is part of both the environmental category of 'Local Issues' (in green) and the safety category of 'Contact with physical agents' (in red). The purple relationship indicates that the environmental impact / health and safety risk takes place in corresponding construction processes. The 'R' relationship indicates that the environmental impact / health and safety risk is related to corresponding work instructions.

Fig. 26. Available information related to the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles).

The developed application allows the verification that the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles) belongs to the environmental category of 'Local Issues' together with the environmental impacts L-1 (dust generation in activities with construction machinery and transport), L-3 (dust generation in activities with cutting operations), L-4 (operations that cause dirtiness at the construction site entrances), L-5

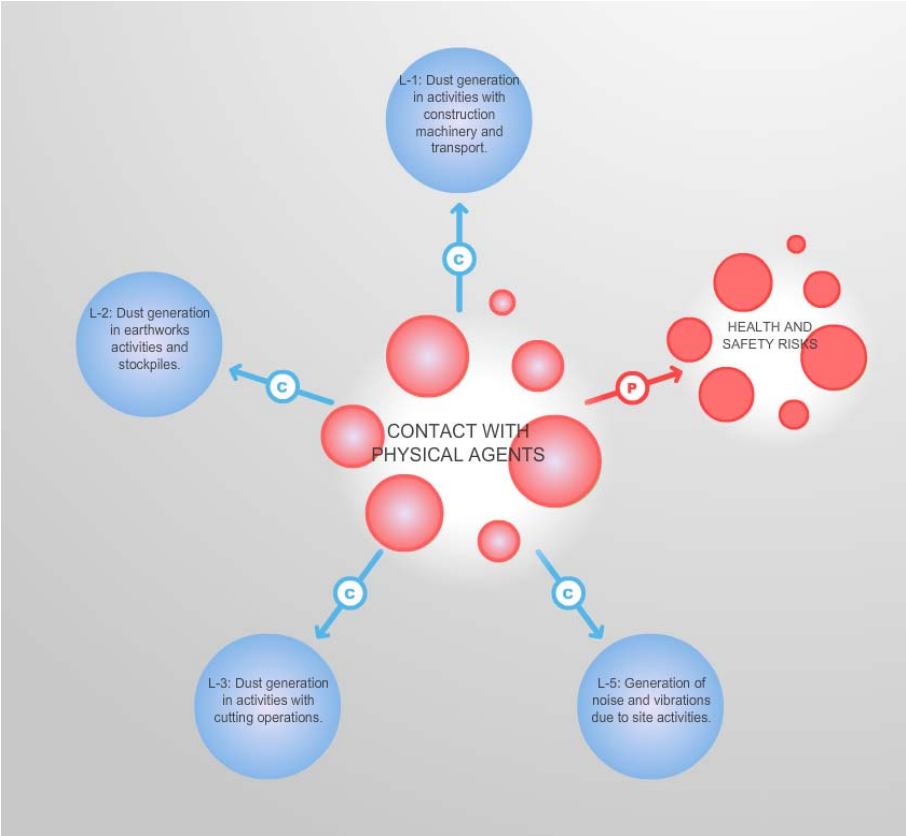
(generation of noise and vibrations due to site activities) and L-6 (landscape alteration by the presence of singular elements) (Fig. 27).



The 'C' relationship indicates that the environmental category contains corresponding environmental impacts. The 'P' relationship indicates that the environmental category is part of an upper class ('Environmental Impacts').

Fig. 27. Relationship between environmental impact L-2 (dust generation in earthworks activities and stockpiles) and its environmental category.

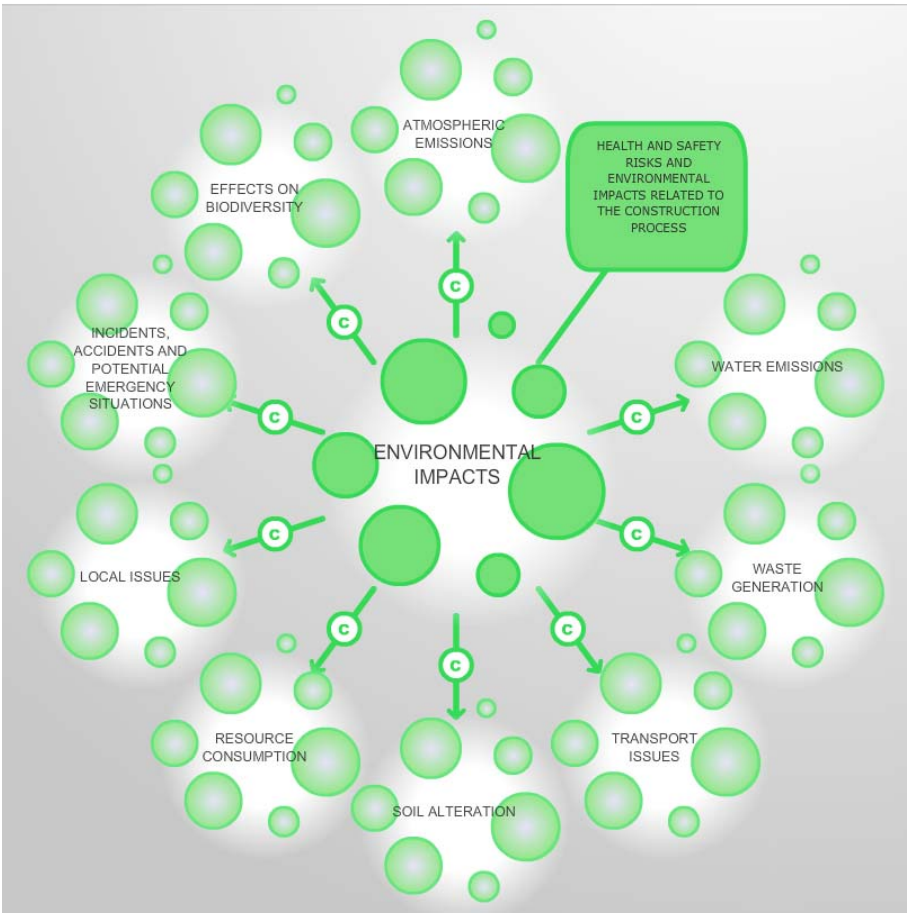
The application also allows the verification that the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles) belongs to the safety category of 'Contact with Physical Agents' together with the health and safety risks L-1 (dust generation in activities with construction machinery and transport), L-3 (dust generation in activities with cutting operations) and L-5 (generation of noise and vibrations due to site activities) (Fig. 28).



The 'C' relationship indicates that the safety category contains corresponding health and safety risks. The 'P' relationship indicates that the safety category is part of an upper class ('Health and Safety Risks').

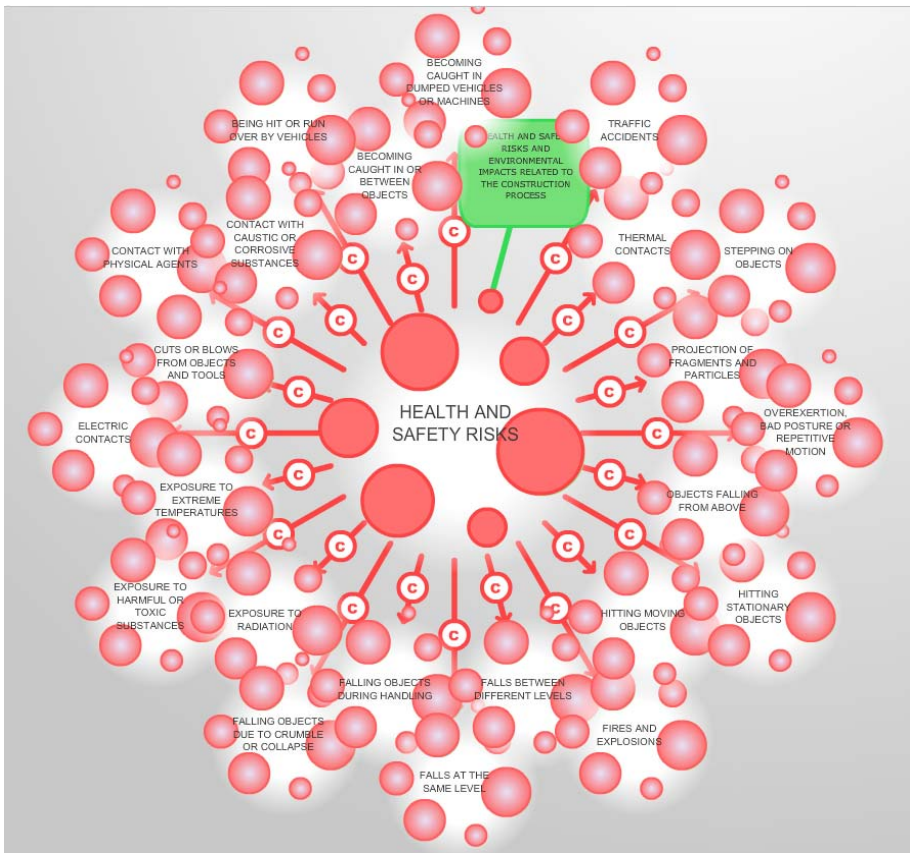
Fig. 28. Relationship between health and safety risk L-2 (dust generation in earthworks activities and stockpiles) and its safety category.

By using the developed ontology-based approach for on-site integrated environmental and health and safety management, it is also possible to substantiate that 'Local Issues' is a subclass of 'Environmental Impacts' and that 'Contact with Physical Agents' is a subclass of 'Health and Safety Risks' (Fig. 29 and 30).



The 'C' relationship indicates that the category of 'Environmental Impacts' contains corresponding subclasses or environmental sub-categories.

Fig. 29. Relationship between the category 'Local Issues' and 'Environmental Impacts'.



The 'C' relationship indicates that the category of 'Health and Safety Risks' contains corresponding subclasses or safety sub-categories.

Fig. 30. Relationship between the category 'Contact with Physical Agents' and 'Health and Safety Risks'.

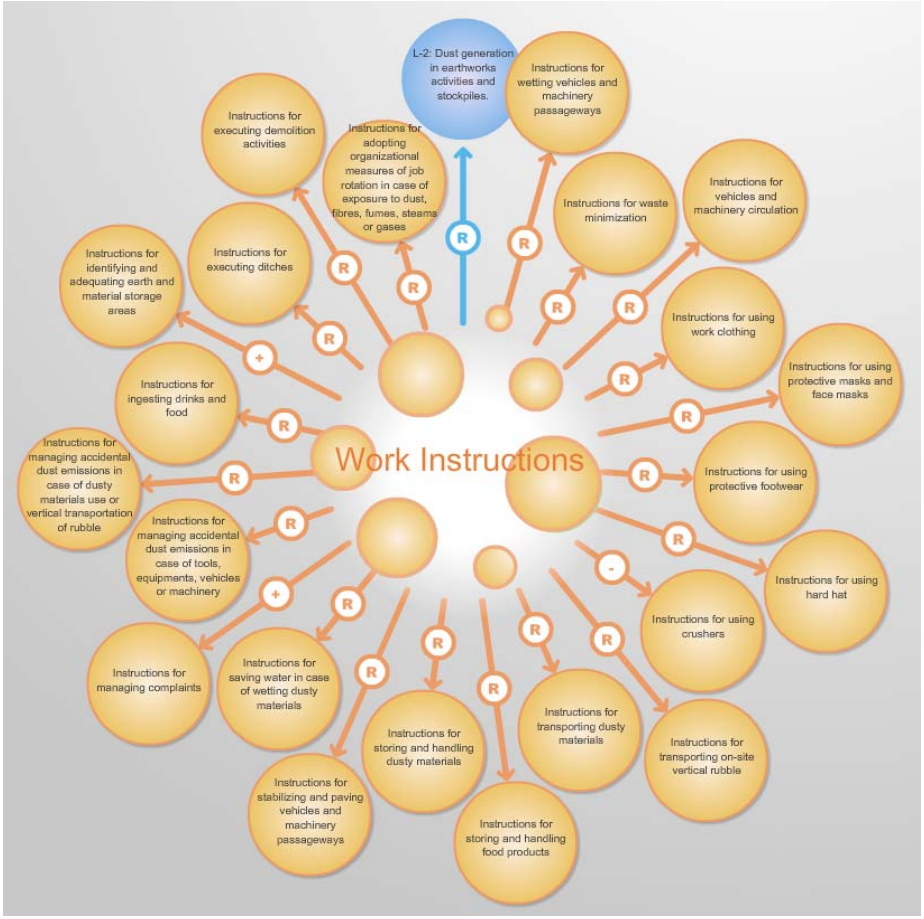
The developed ontology-base approach for on-site integrated environmental and health and safety management shows which work instructions should be implemented during on-site construction activities to lower the significance of a particular environmental impact or health and safety risk. At the same time, the developed application also visualizes potential interference between the application

of other on-site work instructions and a particular environmental impact or health and safety risk. Therefore, and by reviewing the list of work instructions related to a particular environmental impact or health and safety risk, the construction team will be able to identify which on-site work instructions must be implemented and the potential interference of other implemented work instructions. Figure 31 illustrates the relationships for the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles).

Those work instructions with an 'R' relationship ('reduces') should be specifically implemented to reduce the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles). Thus, the construction team is able to identify 19 different work instructions that can be implemented on-site to minimize the potential harmful effects of the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles) (Fig. 31).

At the same time, the implementation of work instructions specifically focused on other environmental impacts or health and safety risks may have a positive effect on the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles). In this case, two work instructions have a '+' relationship: 'instructions for managing complaints' and 'instructions for identifying and arranging earth and material storage areas'. Thus, the construction team can identify that these two work instructions (initially implemented to minimize other environmental impacts or health and safety risks) are tangentially beneficial for the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles) (Fig. 31).

Finally, the application also highlights those work instructions (specifically focused on other environmental impacts or health and safety risks) that may have a negative effect on the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles). In this case and according to figure 31, the application highlights one '-' relationship, corresponding to 'instructions for using crushers'. Thus, the construction team is aware that the on-site implementation of a work instruction for using crushers may be detrimental for the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles) (Fig. 31).



The 'R' relationship indicates that the environmental impact / health and safety risk is reduced by the corresponding work instructions. The '+' relationship indicates that the environmental impact / health and safety risk is positively affected by corresponding work instructions. The '-' relationship indicates that the environmental impact / health and safety risk is negatively affected by corresponding work instructions.

Fig. 31. Identification of work instructions related to the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles).

The developed application can also prove that the effect of an implemented on-site work instruction on other environmental impacts or health and safety risks.

According to figure 32, 'instructions for using crushers' clearly reduces environmental impacts WG-3 (generation of inert waste) and RC-4 (raw materials consumption during the construction process).

The 'R' relationship indicates that the work instruction reduces corresponding environmental impacts and health and safety risks. The '-' relationship indicates that the work instruction negatively affects corresponding environmental impacts / health and safety risks.

Fig. 32. Identification of environmental impacts and health and safety risks related to the work instruction 'instructions for using crushers'.

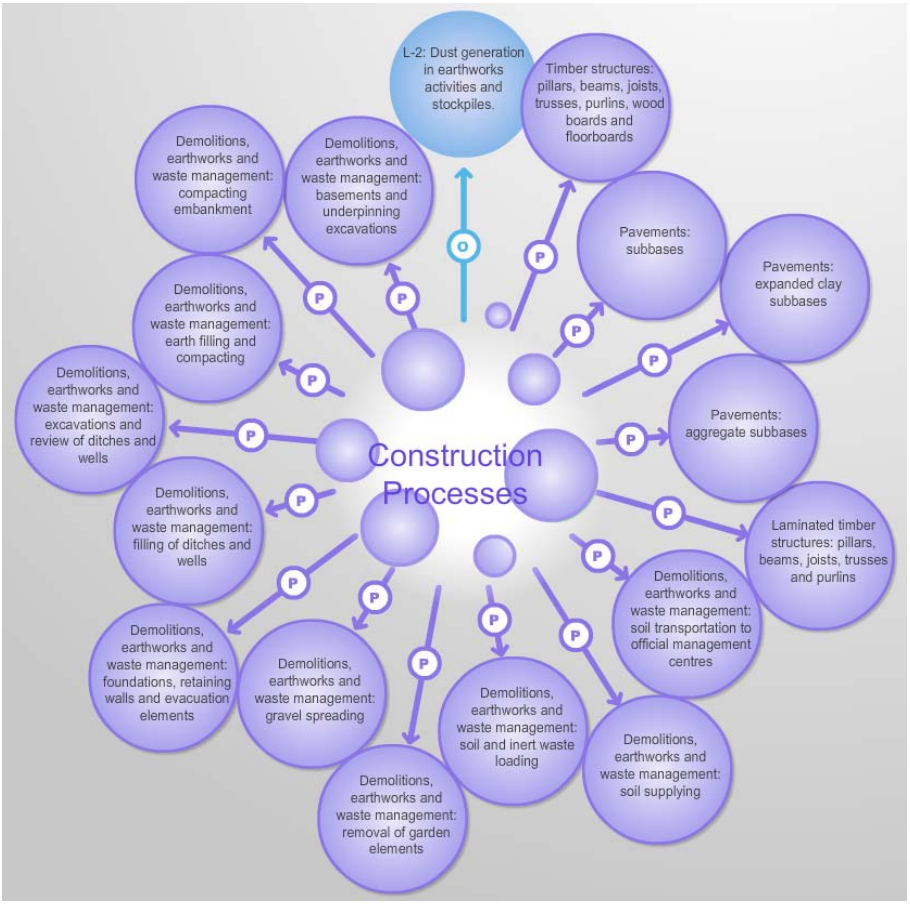
However, the on-site implementation of a work instruction for using crushers is tangentially detrimental for environmental impacts SA-1 (land occupancy by the

building, provisional on-site facilities and storage areas), RC-3 (fuel consumption during the construction process) and AE-1 (generation of greenhouse gas emissions due to construction machinery and vehicle movements) and environmental impacts / health and safety risks L-2 (dust generation in earthworks activities and stockpiles) and L-5 (generation of noise and vibrations due to site activities). Thus, the construction team can identify advantages and drawbacks related to the on-site implementation of a work instruction for using crushers (Fig. 32).

The developed ontology-based approach for on-site integrated environmental and health and safety management is also able to visualize which construction processes may cause a particular environmental impact or health and safety risk. Figure 33 shows construction processes related to the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles). By reviewing the list of related construction processes where an environmental impact or health and safety risk may take place, the construction team can identify when corresponding on-site work instructions should be implemented.

Finally, the application is also able to visualize which environmental impacts and health and safety risks are related to a particular construction process. In this case, and for 'demolitions, earthworks and waste management: soil and inert waste loading', the application shows seven health and safety risks (in red), six environmental impacts (in green) and two other risks that apply to both the environmental and the health and safety domains (in blue) (Fig. 34).

Having identified those construction processes with higher significant environmental impacts and health and safety risks, the application can also be used to help the construction team to plan the timing and frequency of inspections.



The 'P' relationship indicates that the environmental impact / health and safety risk takes place in corresponding construction processes.

Fig. 33. Identification of the construction processes related to the environmental impact / health and safety risk L-2 (dust generation in earthworks activities and stockpiles).

The 'O' relationship indicates that the construction process origins or causes corresponding environmental impacts / health and safety risks.

Fig. 34. Identification of environmental impacts and health and safety risks related to the construction process 'demolitions, earthworks and waste management: soil and inert waste loading'.

5.6 Conclusions

The process of implementing an IMS always begins with the planning stage. During this step, the organization shall identify the aspects of its activities, products and services that are relevant to the scope of the MS and to evaluate the risks to the organization by determining and recording those aspects that have or can have a significant impact. The methodology described in chapter 4 provides an integrated approach to determine the significance of potential environmental impacts and health and safety risks at the pre-construction stage (corresponding to the planning stage of the implementation process of an IMS) for a particular construction project (Fig. 35).

During the implementation and operation stage, the organization shall ensure that the operations that are associated with significant aspects are carried out under controlled conditions in order to meet the policies and objectives of the organization as well as legal and other applicable requirements. Chapter 5 takes an essential step in formalizing the theoretical framework needed to enhance the implementation of IMSs in construction companies through integrated operational control, using an ontology-based approach as a technical solution (Fig. 35).

Therefore, the main outcome of this chapter is to provide a guidance tool for effective on-site integrated environmental and health and safety management through the development of an ontology-based approach.

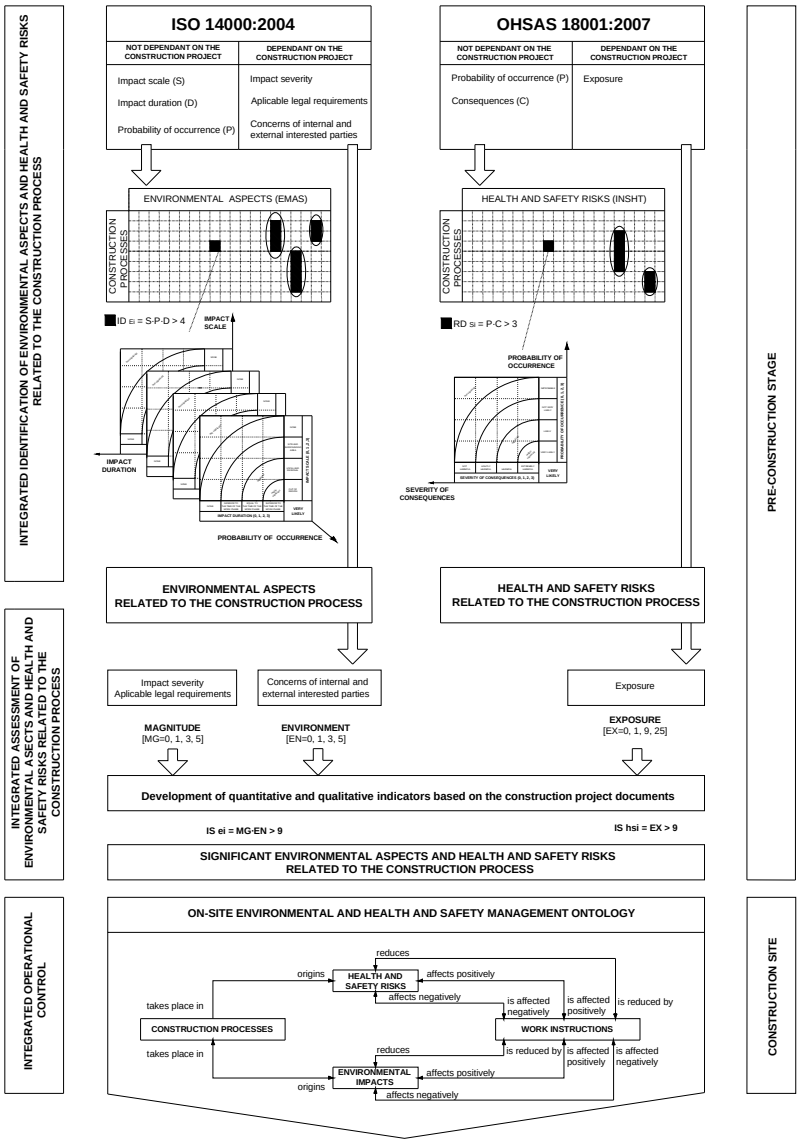


Fig. 35. Overview of the developed methodology.

The building process of the ontology-based approach was strongly influenced by the methodology provided by Noy and McGuiness (2001). The first step consisted of determining the domain and scope of the developed approach. Secondly, existing ontologies were revised but unfortunately no resources were judged to be suitable for the purpose of this dissertation. The third step of the ontology-based approach building process consisted of identifying key concepts related to the integrated operational control of environmental impacts and health and safety risks. Analysing the requirements stated in ISO 14001:2004 and OHSAS 18001:2007 under the subsection of operational control, construction processes, environmental impacts, health and safety risks and work instructions were identified as key concepts. These key concepts, formalized as classes, entailed their own hierarchies which had to be developed. Classes and class hierarchy corresponding to the major classes 'Construction Processes', 'Environmental Impacts' and 'Health and Safety Risks' were derived according to the methodology developed in chapter 4. Classes and class hierarchy for the major class 'Work Instructions' were obtained by extracting important concepts from the analysis of two reference documents. Concepts within these hierarchies were associated through the relationship 'a kind of' (or the inverse relationship 'is a'). In the forth step, properties were used to associate concepts from each hierarchy to other hierarchies. For example, an environmental impact takes place in a construction process and that is stated as a relationship in the conceptual model. In a similar way, relationships in the conceptual model also represent the fact that the implementation of a particular on-site work instruction may reduce an environmental impact. In this case, constraints on the value of the properties did not need to be stated. The last step included the creation of individual instances of classes in the hierarchy. This step allows the universalization of the developed ontology-based approach since creating instances of classes facilitates the semantically matching of work instructions already existing in any construction company to the developed classes and subclasses. The current version of the ontology-based approach for on-site integrated environmental and health and safety management has four major classes and about 748 subclasses and sub-subclasses and 6,105 established relationships between classes.

After having successfully completed the validation process, the developed ontology-based approach was implemented through an open source radial browser as it allowed displaying complex concept network structures in an intuitive manner. The developed application can be accessed at https://gric.upc.es/integracio/.

The main benefit of the proposed ontology-based approach includes providing a comprehensive framework for enhancing the implementation of IMSs in construction companies through integrated operational control. The ontological map for on-site environmental and health and safety management also allows gaining a better understanding of practical considerations of on-site environmental and health

and safety management, systematically considering the interactions between both domains.

The developed ontology-driven solution can be used as a framework for contractors to effectively manage environmental impacts and health and safety risks during the construction of their projects, specially giving support on the implementation of necessary control measures to lower both safety hazards and environmental impacts to an acceptable level.

By reviewing the list of work instructions related to a particular environmental impact or health and safety risk, the construction team will be able to identify which on-site work instructions must be implemented in order to either avoid a possible environmental impact or health and safety risk before it occurs or to minimise its negative effect when it does. At the same time, the ontology-based approach for on-site integrated environmental and health and safety management visualizes potential interference between the application of other on-site work instructions and a particular environmental impact or health and safety risk. Therefore, the developed ontology-based approach allows verifying the effect of an implemented on-site work instruction on other environmental impacts or health and safety risks. Thus, by reviewing the list of related construction processes where the environmental impact or the health and safety risk may take place, the construction team can identify when corresponding on-site work instructions should be implemented. Finally, the ontology-based approach is also able to visualize which environmental impacts and health and safety risks are related to a particular construction process. Having identified those construction processes with higher significant environmental impacts and health and safety risks, the developed ontology-based approach can also be used to help the construction companies to plan the timing and frequency of inspections.

Benefits of the proposed solution also include clarifying the structure of knowledge related to the integrated on-site environmental and health and safety management and enabling knowledge sharing between not only domain experts but also between the several stakeholders simultaneously involved in a construction site. The ontology-based approach for on-site integrated environmental and health and safety management may also contribute to addressing the existing dichotomy between tacit and explicit knowledge.

Moreover, recording environmental and health and safety incidences using the developed ontology-driven solution allows the construction company to conduct statistical studies on its environmental and health and safety performance. Such analysis can identify the most frequent activities generating environmental and

safety incidences and the most implemented on-site work instructions. This will assist the project team in learning from the experience of completed projects.

In addition, this development also demonstrates a practical application of ontologies within the field of on-site environmental and health and safety management. However, it must be taken into account that there is no single correct ontology for any domain as potential applications of the ontology and the designer's understanding of the domain undoubtedly affect the ontology design process.

Chapter 6

Evaluation of the methodology

6.1 Introduction

This dissertation focuses on the development of a quantitative methodology for predicting and assessing the environmental impacts and the health and safety risks associated with the construction of new residential buildings during the pre-construction stage. The methodology was developed to provide designers with a risk-analysis-based way of evaluating the environmental and safety-related performance of their residential construction designs and to help construction companies improve their on-site environmental and safety performance.

The objective of this chapter is to document the verification and the validation of this methodology and the corresponding web-based implementation tool. Four types of validity have been investigated: conceptual methodology validation, data validation, computerized methodology verification and, operational validity. Two different case studies have been randomly chosen to operationally validate the developed methodology; therefore, each case study focuses on evaluating different aspects of the approach.

Case studies also illustrate practical uses of the methodology presented in this dissertation, demonstrating how environmental and health and safety elements can be intrinsically adopted as part of the project design, planning and construction.

6.2 Verification and validation of the methodology

The approach used to methodology evaluation is based on four steps (Fig. 36). The first step includes the conceptual methodology validation, which is focused on the analysis of objectives, scope, assumptions and outputs of the methodology. The second step is data validation, which is concerned with assessing the use of complete, appropriate, accurate and consistent data. The third step deals with the computerized methodology verification and addresses such issues as the correct computer programming and implementation of the conceptual methodology. Finally, the fourth step includes operational validation, which is concerned with determining that the output of the methodology has the required accuracy.

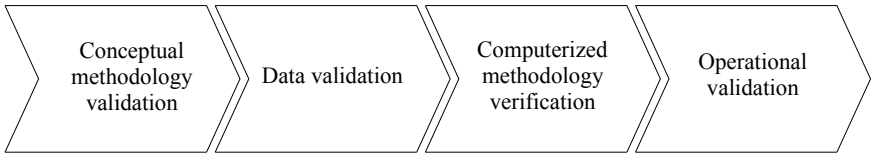


Fig. 36. Verification and validation of the methodology.

6.2.1 Conceptual methodology validation

According to Sargent (1998), conceptual methodology validation is determining that the theories and assumptions underlying the conceptual methodology are correct and reasonable for the intended purpose of the methodology.

The developed methodology has been published in Building and Environment (Gangolells et al., 2009) and it has been accepted for publication in the Journal of Safety Research. Since both journals include a peer-review process to select the articles they publish, it can be stated that the developed methodology has been examined by several knowledgeable people. Therefore, it can be assumed that the conceptual methodology (in terms of objectives, scope, assumptions and outputs) was considered reasonable and correct by these experts.

6.2.2 Data validation

According to Sargent (1998), data validation may be defined as ensuring that the data necessary for methodology building, evaluation and testing are adequate and correct. Therefore, data validation covers such issues as data quality and parameter

calibration. Hence, reliance on complete, appropriate, accurate and consistent data is assessed.

In this case, the proper building of the methodology involved using only those data available in construction project documents as the development of indicators and, particularly, the formulation of significance limits was based on the statistical analysis of several real new-start construction projects. Data sources where specifically checked (Tables A.1, A.2 and A.3), verifying that all developed indicators could be extracted from the project documents (building specifications, drawings, bill of quantities, budget, health and safety plan, etc.).

It is also important to highlight that the developed methodology is intrinsically appropriately calibrated to the observed market behaviour, as current performance levels in construction projects were taken as a baseline for formulating significance limits.

In order to ensure that appropriate and accurate data were used, procedures for collecting and maintaining them were developed. First of all, several Excel® spreadsheets were designed in order to calculate corresponding environmental and health and safety indicators for each construction project. When calculating the significance limits for each developed indicator, several Excel® spreadsheets were also designed. In this case, each spreadsheet grouped corresponding numerical values obtained during the assessment of the 55 real new-start construction projects for a particular indicator. In this way, collected data were tested using techniques such as internal consistency checks.

According to Fellows and Liu (2008), and in order to ensure that the data necessary for methodology evaluation and testing were adequate and correct, only those real construction projects which had not been employed in building the methodology were chosen as case studies (see section 6.2.4). Thus, the tests were independent.

6.2.3 Computerized methodology verification

Verification is typically viewed as the systematic testing of software systems to find and correct errors (East et al., 2008). Therefore, computerized methodology verification ensures that the computer programming and the implementation of the conceptual methodology are correct (Sargent, 1998).

After the software was developed and implemented, the web-based implementation tool was tested for correctness and accuracy by the program developer. The computerized methodology was performed under different conditions and the

resulting values were used to determine if the computer program and its implementation were correct.

The computerized methodology was used during the operational validation, and thus, assuming that the original data were valid, any deficiencies found were ascribed to an improperly programmed or implemented methodology.

Finally, the web-based implementation was found to operate according to the conceptual methodology.

6.2.4 Operational validation

According to Sargent (1998), operational validity is concerned with determining that the output behaviour of the methodology has the accuracy required to the intended purpose or applicability of the methodology.

The major attribute affecting operational validity is whether the original system is observable, where observable means it is possible to collect data on operation behaviour of the system (Sargent, 1998). In this sense, and according to East et al. (2008), one of the major difficulties in construction research is the lack of test cases upon which research results may be verified and validated. Construction projects are expensive and therefore, testing design alternatives or planning strategies is, in most cases, unfeasible. Actually, design and planning alternatives are deliberated implicitly, within the minds of designers and planners using undefined criteria for selection. In addition, within the construction management research areas, there are limited data sets upon which work may be based (East et al., 2008).

In case of non-observable systems, existing literature suggests the comparison of the developed methodology to other existing methodologies (Sargent, 1998). However, and as stated in chapter 3, no relevant approaches for simultaneously integrating aspects of environmental and health and safety management during the construction design and planning stages have been found in the existing literature. Therefore, the developed methodology cannot be compared to other methodologies previously validated.

Previous authors also suggest exploring methodology behaviour, which involves examining the output behaviour of the methodology using appropriate validation techniques (Sargent, 1998; Fellows and Liu, 2008). In this case, validation techniques usually include parameter variability-sensitivity analysis (Sargent, 1998), consisting of changing the values of the input of the methodology to determine the effect upon the behaviour of the methodology and its output.

In this case, validation was performed based on the application of the proposed methodology in two different construction projects. These construction projects were randomly selected without predefining any specific characteristic. Each case study focuses on evaluating different aspects of the approach (Table 12). The first one focuses on the application of the methodology during the design stage of a multi-family dwelling whereas the second one reports the application of the methodology during the planning stage of a single-family construction project.

Stage	Case study 1	Case study 2
Design stage	Multi-family dwelling	
Construction planning stage		Single-family house

Table 12. Summary map of the reported case studies for methodology validation.

6.2.4.1 Case study 1

This section applies the developed methodology to the design process of a multi-family construction project. In this case, client's requirements include designing an isolated four-storey building with one underground car park floor. Due to urban constraints, the building's floor area cannot exceed 2,241.18 m^2, and it can contain a maximum of 19 dwellings.

One of the first choices might lie between designing an in-situ concrete structure or a precast concrete structure. The safety risk level of designing an in-situ concrete structure was found to be 108 whereas the safety risk level of designing a precast structure was found to be 36. Table 13 summarizes the results of the safety evaluation of both design alternatives whereas Table D.1 shows corresponding detailed results.

Designing a precast structure instead of an in-situ concrete structure significantly reduces risks FS-2 (falls at the same level during reinforcement work), FOC-2 (injuries from falling objects due to crumble or collapse due to the use of in-situ concrete), OF-3 (injuries from objects falling from above during structural work), SO-3 (injuries from stepping on reinforcing bars, screws or nails), HS-4 (injuries from hitting stationary objects during structural work), HM-4 (injuries from hitting moving parts of machinery during structural work), CS-2 (injuries from cuts or blows from objects and tools during work on foundation and structure), CO-6 (injuries from becoming caught in or between objects in forming and shoring

operations), EH-3 (injuries from exposure to harmful or toxic substances due to the use of concrete release agents at the construction site) and CC-1 (injuries from contact with caustic or corrosive substances during work on foundations and in-situ concrete structures). However, designing a precast concrete structure instead of an in-situ concrete structure causes two other safety risks: FOH-2 (injuries from falling objects during handling in prefabricated structure assembly) and HV-4 (injuries from being hit or run over by vehicles in prefabricated structure assembly).

The environmental impact level of designing an in-situ concrete structure was found to be 41 whereas the environmental impact level of designing a precast structure was found to be 28. Table 13 summarizes the results of the environmental evaluation of both design alternatives whereas Table D.2 shows corresponding detailed results.

Designing a precast structure instead of an in-situ concrete structure significantly reduces environmental impacts SA-2 (use of concrete release agent at the construction site), RC-1 (water consumption during the construction process), L-6 (Landscape alteration by the presence of singular elements) and T-2 (interference in external road traffic due to the construction site). Some other environmental impacts, such as WE-2 (dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids) included within the category of water emissions and SA-6 (dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids) included within the category of soil alteration are also slightly reduced with this design alternative.

The choice of roof type may also have safety implications. According to the results shown in Table D.3, executing a trafficable roof with boundary walls involves half the safety risk level related to the execution of a slate gable roof with a slope of 45% and windows for ventilation. In fact and according to the developed methodology, the safety risk level related to the execution of a trafficable roof with boundary walls is 27 whereas the safety risk level related to the execution of a slate gable roof with a slope of 45% and windows for ventilation is 61 (Table 13).

DESIGN ALTERNATIVES	SAFETY RISK LEVEL	ENVIRONMENTAL IMPACT LEVEL
In-situ concrete structure.	108	41
Precast concrete structure.	36	28
Slate gable roof with slope of 45% and windows for ventilation.	61	-
Trafficable roof with boundary walls.	27	-

DESIGN ALTERNATIVES	SAFETY RISK LEVEL	ENVIRONMENTAL IMPACT LEVEL
Facing brick*	133	48
Masonry walls with natural stone cladding*	116	24
Masonry walls with single-layer mortar coating*	75	33
Precast concrete facades*	49	8
Balconies with wood railings.	34	-
Balconies with boundary walls.	18	-
Natural wood floors.	9	-
Artificial wood floors.	0	-
Waterproof layer joints sealed off by applying heat.	18	-
Waterproof layer joints sealed off by mechanical means.	0	-
Window closures: 2 m wide per 2 m of height.	25	-
Window closures: 0.80 m wide per 0.80 m of height.	9	-
Recycled content in raw materials not planned.	-	5
Recycled content in raw materials up to 50%.	-	1
Waste management not planned.	-	75
Waste management planned, stressing in-situ reuse.	-	15
Not dependant on the abovementioned alternatives.	256	83

48

* In case of dry partition walls.

Table 13. Case study 1: overview of the assessment results.

The execution of a trafficable roof with boundary walls reduces construction safety risks FH-3 (falls between different levels during roof work) and FS-3 (falls at the

same level during roof work). Safety risks OF-4 (injuries from objects falling from above during roof work), and CS-3 (injuries from cuts or blows from objects and tools during finishing work on roofs) are also reduced as a result of this design alternative. Construction safety risk FH-2 (falls between levels during structural works) is also slightly reduced with this design alternative.

Within the environmental domain, the choice of roof type does not involve significant changes (Table 13).

Four of a number of alternative designs for the external facades of the building are taken into account. In the first three design alternatives, the external facades are primarily three-layer masonry walls. The first design alternative includes facing brick wall, the second one has natural stone cladding, and the third one has a single-layer mortar coating. The fourth alternative includes designing precast concrete panels without in-situ claddings. According to Table 13 and Table D.4, the highest safety risk level corresponds to the facing brick facade (133), followed by the masonry wall with natural stone cladding (116) and the masonry wall with single-layer mortar coating (75). Finally, the safety risk level of designing precast concrete panels without in-situ claddings is 49.

Designing precast concrete panels without in-situ claddings reduces some safety risks, such as FOC-3 (injuries from falling objects due to crumble or collapse during cladding work on facades), FOH-3 (injuries from falling objects during handling in cladding work), CS-5 (injuries from cuts or blows from objects and tools during work on coatings or floors), FF-1 (injuries from projection of fragments and particles in cutting operations), FF-3 (injuries from projection of fragments and particles in spray-gun painting operations), CC-2 (injuries from contact with caustic or corrosive substances during work on brick closures and coatings) and L-3 (dust generation in activities with cutting operations). Safety risk L-3 also applies to the environmental domain. Construction safety risks FH-4 (falls between different levels during work on facades, partition walls and vertical coatings), OF-5 (injuries from objects falling from above during work on facades and vertical coatings) are also slightly reduced with this design alternative.

The highest environmental impact level corresponds to the facing brick facade (48), followed by the masonry wall with single-layer mortar coating (33) and the masonry wall with natural stone cladding (24). Finally, the environmental impact level of designing precast concrete panels without in-situ claddings is 8. Table 13 summarizes these results and Table D.5 shows detailed results of the environmental evaluation of the four design alternatives.

Designing precast concrete panels without in-situ claddings reduces some environmental impacts, such as AE-2 (emission of VOCs and CFCs), SA-3 (use of

cleaning agents or surface-treatment liquids at the construction site), and L-3 (dust generation in activities with cutting operations). This environmental impact also applies to the health and safety domain.

Suppose a choice is to be made between designing balconies with wood railings and designing balconies with boundary walls. The safety risk level of designing balconies with wood railings was found to be 34 whereas the safety risk level of designing balconies with boundary walls was found to be 18 (Table 13). Table D.6 shows detailed results of the safety evaluation of both design alternatives.

The second alternative would clearly reduce risk FH-5 (falls between different levels during floor work) and FH-6 (falls between different levels during work on door and window closures), although in this case the exposure rating would not change.

The choice of designing balconies with wood railings or boundary walls does not involve significant changes in the environment impact level (Table 13).

Other minor design decisions may also have different safety implications. For example, designing an artificial wood floor that does not require polishing instead of a natural one reduces risk EH-6 (injuries from exposure to harmful or toxic substances in surface-polishing operations) from 9 to 0 (Tables 13 and D.7).

Sealing the waterproof layer joints mechanically instead of by applying heat reduces two other safety risks: TC-2 (injuries from thermal contacts due to joining waterproof membranes) and EH-4 (injuries from exposure to harmful or toxic substances due to joining waterproof membranes), both from 9 to 0 (Tables 13 and Table D.8).

Likewise, reducing the size of the windows (from windows of 2 m wide per 2 m of height to windows of 0.80 m wide per 0.80 m of height) could minimize risk FOH-4 (injuries from falling objects during handling in work on door and window closures) from 25 to 9 (Tables 13 and D.9).

Other design decisions may decrease the environmental impact level of the construction project. Including the use of recycled materials (up to 50%) in the construction project reduces environmental impact RC-4 (raw materials consumption during the construction process) from 5 to 1 (Tables 13 and D.10).

In the same way, the assessment of the environmental-related performance of a construction project may decrease from 75 to 15 in case of setting up an effective waste management plan and planning the inclusion of reused elements in the new-start construction project (Tables 13 and D.11).

Finally, tables D.12, D.13 and D.14 include detailed results corresponding to the assessment of those construction safety risks and environmental impacts not dependent on the abovementioned design alternatives.

Obviously each design alternative tends to provide different benefits and to have different safety and environmental implications. The overall safety risk level of this construction project may range from 486 in the safest design (precast concrete structure, trafficable roof with boundary walls, precast concrete facades, balconies with boundary walls, artificial wood floors, waterproof layer joints sealed off by mechanical means and reduced size of windows closures -0.80 m per 0.80 m-) to 649 in the lowest safety design (in-situ concrete structure, slate gable roof with slope of 45% and windows for ventilation, facing brick facades, balconies with wood railings, natural wood floors, waterproof layer joints sealed off by applying heat and windows more than 1 m wide per 1 m of height). Similarly, the overall environmental impact level of this construction project may range from 187 in the most eco-friendly design (precast concrete structure, precast concrete facades, recycled content in raw materials up to 50% and inclusion of reused elements) to 296 in the lowest eco-friendly design (in-situ concrete structure, facing brick facades and no inclusion of recycled raw materials neither reused elements).

Designers may assume different environmental impact levels and safety risk levels in the final design as the methodology highlights the significant remaining environmental impacts and health and safety risks and measures can then be implemented at the construction site.

6.2.4.2 Case study 2

This section applies the developed methodology to the construction planning stage. The final construction project included one single-family house of 301.65 m^2 of floor area. The ground floor, with 154.25 m^2, included a kitchen, a dining-living room, one toilet, one single bedroom and one double bedroom with a bathroom and a dressing room. The first floor, with 148.40 m^2 of floor area, included three bedrooms, two bathrooms and a big terrace. The townhouse was located in a residential area without immediate historic-artistic buildings.

The structure was primarily a cast-in-situ reinforced concrete frame, consisting of concrete columns positioned according to a regular grid with bidirectional reinforced concrete slabs. The structure rested on superficial foundations (strip footings under the walls and isolated footings under the columns). The building had a gable roof with a slope of 25% on one side and a trafficable roof on the other side. The external facades were masonry walls. Most of the facades had a single-layer mortar coating and a stone surface external cladding, and the rest was a facing brick wall. Windows

were made of aluminium and balconies had wood railings. Masonry bricks with a plastered finish were used in the construction of almost all the internal partitions. Ceilings had also a plastered finish, whereas the floor was made from natural wood. Kitchen, bathrooms and toilets were completely tiled and had false ceilings.

During the construction planning stage, part of the provisional on-site facilities and storage areas were planned to be placed on the sidewalk and part of the street, being the site occupation initially estimated on 170.63 m^2. Water and electricity networks were available in the construction site. No use of special machinery was planned and construction works were expected to be carried out during daytime hours. In general, no specific environmental procedures were initially planned by the contractor.

Within the health and safety domain, construction safety risks FH-4 (falls between different levels during work on facades, partition walls and vertical coating), FS-3 (falls at the same level during roof work) and FS-4 (falls at the same level during work on partition walls and vertical coatings) were found to be significant. Unacceptable levels for construction safety risks FOC-2 (injuries from falling objects due to crumble or collapse due to the use of in-situ concrete), FOH-1 (injuries from falling objects during materials and waste management operations) and FOH-4 (injuries from falling objects during handling in work on door and window closures) were also highlighted by the developed methodology. The significance of construction safety risks OF-1 (injuries from objects falling from above during materials and waste management operations), OF-3 (injuries from objects falling from above during structural work) and OF-6 (injuries from objects falling from above during work on partition walls and vertical coatings) were also found to be greater than 9. The assessment of this construction project also allowed to identify construction safety risks SO-3 (injuries from stepping on reinforcing bars, screws or nails), HS-4 (injuries from hitting stationary objects during structural work), HM-1 (injuries from hitting moving parts of machinery during materials and waste management operations) and HM-4 (injuries from hitting moving parts of machinery during structural work) as potentially significant risks. Finally, safety risks CS-2 (injuries from cuts or blows from objects and tools during work on foundation and structure), CS-3 (injuries from cuts or blows from objects and tools during finishing work on roofs), CO-1 (injuries from becoming caught in or between objects during materials and waste management operations), CO-6 (injuries from becoming caught in or between objects in forming and shoring operations) and CV-1 (injuries from becoming caught in dumped vehicles or machines during materials and waste management operations) were also found to be significant. Detailed assessment results are shown in Tables 14 and D.15.

CONSTRUCTION SAFETY RISK / ENVIRONMENTAL IMPACT		SG
FH-1	Falls between different levels during small demolition operations, earthworks and foundation work.	9
FH-2	Falls between different levels during structural work.	9
FH-3	Falls between different levels during roof work.	9
FH-4	Falls between different levels during work on facades, partition walls and vertical coatings.	**25** / 9
FH-5	Falls between different levels during floor work.	9
FH-6	Falls between different levels during work on door and window closures.	9
FH-7	Falls between different levels during work on false ceilings and ceiling coatings.	9
FS-1	Falls at the same level during small demolition operations and earthworks.	9
FS-2	Falls at the same level during reinforcement work.	9 / 9
FS-3	Falls at the same level during roof work.	**25**
FS-4	Falls at the same level during work on partition walls and vertical coatings.	**25**
FOC-1	Injuries from falling objects due to crumble or collapse during earthworks.	9
FOC-2	Injuries from falling objects due to crumble or collapse due to the use of in-situ concrete.	**25**
FOC-3	Injuries from falling objects due to crumble or collapse during cladding work on facades.	9
FOC-4	Injuries from falling objects due to crumble or collapse during cladding work on partition walls.	1
FOC-5	Injuries from falling objects due to crumble or collapse during false ceiling work.	9
FOH-1	Injuries from falling objects during materials and waste management operations.	**25**
FOH-2	Injuries from falling objects during handling in prefabricated structure assembly.	0
FOH-3	Injuries from falling objects during handling in cladding work.	9
FOH-4	Injuries from falling objects during handling in work on door and window closures.	**25**
OF-1	Injuries from objects falling from above during materials and waste management operations.	**25**
OF-2	Injuries from objects falling from above during earthworks.	9
OF-3	Injuries from objects falling from above during structural work.	**25**
OF-4	Injuries from objects falling from above during roof work.	9
OF-5	Injuries from objects falling from above during work on facades and vertical coatings.	9
OF-6	Injuries from objects falling from above during work on partition walls and vertical coatings.	**25**
OF-7	Injuries from objects falling from above during false ceiling work.	9
SO-1	Injuries from stepping on objects during small demolition operations.	0
SO-2	Injuries from stepping on objects during removal of garden elements.	9
SO-3	Injuries from stepping on reinforcing bars, screws or nails.	**25** / 9
HS-1	Injuries from hitting stationary objects in provisional on-site facilities and storage areas.	9
HS-2	Injuries from hitting stationary objects during small demolition operations.	0
HS-3	Injuries from hitting stationary objects during removal of garden elements.	9
HS-4	Injuries from hitting stationary objects during structural work.	**25**
HM-1	Injuries from hitting moving parts of machinery during materials and waste management operations.	**25**
HM-2	Injuries from hitting moving parts of machinery during earthworks.	9

CONSTRUCTION SAFETY RISK / ENVIRONMENTAL IMPACT		SG
HM-3	Injuries from hitting moving parts of machinery during foundation work.	9
HM-4	Injuries from hitting moving parts of machinery during structural work.	**25**
HM-5	Injuries from hitting moving parts of machinery during work on concrete foundations and floors.	9
CS-1	Injuries from cuts or blows from objects and tools during removal of garden elements.	9
CS-2	Injuries from cuts or blows from objects and tools during work on foundation and structure.	**25**
CS-3	Injuries from cuts or blows from objects and tools during finishing work on roofs.	**25**
CS-4	Injuries from cuts or blows from objects and tools during work on facades and partition walls.	9
CS-5	Injuries from cuts or blows from objects and tools during work on coatings or floors.	9 / 1
CS-6	Injuries from cuts or blows from objects and tools during work on false ceilings.	9
FF-1	Injuries from projection of fragments and particles in cutting operations.	9 / 9 / 1
FF-2	Injuries from projection of fragments and particles in concrete operations.	9
FF-3	Injuries from projection of fragments and particles in spray-gun painting operations.	0
CO-1	Injuries from becoming caught in or between objects during materials and waste management operations.	**25**
CO-2	Injuries from becoming caught in or between objects during small demolition operations.	0
CO-3	Injuries from becoming caught in or between objects during removal of garden elements.	9
CO-4	Injuries from becoming caught in or between objects during earthworks.	9
CO-5	Injuries from becoming caught in or between objects during work on piles, micro-piles and screen walls.	0
CO-6	Injuries from becoming caught in or between objects in forming and shoring operations.	**25**
CO-7	Injuries from becoming caught in or between objects in operations with scaffoldings or working platforms.	9
CV-1	Injuries from becoming caught in dumped vehicles or machines during materials and waste management operations.	**25**
CV-2	Injuries from becoming caught in dumped vehicles or machines during earthworks.	9
CV-3	Injuries from becoming caught in dumped vehicles or machines during foundation work.	9
CV-4	Injuries from becoming caught in dumped vehicles or machines during structural work.	1
CV-5	Injuries from becoming caught in dumped vehicles or machines during pavement work.	9
OX-1	Injuries form overexertion, bad posture or repetitive motion.	9
ET-1	Injuries from exposure to extreme temperatures.	0
TC-1	Injuries from thermal contacts due to specific welding operations.	0
TC-2	Injuries from thermal contacts due to joining waterproof membranes.	9
EC-1	Injuries from electrical contacts with active elements.	9
EC-2	Injuries from electrical contacts due to breakage of underground electric power cables.	0
EC-3	Injuries from electrical contacts due to contact with balling pumps.	0
EC-4	Injuries from electrical contacts due to contacts with overhead electric power lines.	0

CONSTRUCTION SAFETY RISK / ENVIRONMENTAL IMPACT		SG
EH-1	Injuries from exposure to harmful or toxic substances during materials and waste management operations.	9
EH-2	Injuries from exposure to harmful or toxic substances during specific welding operations.	0
EH-3	Injuries from exposure to harmful or toxic substances due to the use of concrete release agents at the construction site.	9
EH-4	Injuries from exposure to harmful or toxic substances due to joining waterproof membranes.	9
EH-5	Injuries from exposure to harmful or toxic substances due to the use of synthetic paints and varnishes.	0
EH-6	Injuries from exposure to harmful or toxic substances in surface-polishing operations.	9
CC-1	Injuries from contact with caustic or corrosive substances during work on foundations and in-situ concrete structures.	9
CC-2	Injuries from contact with caustic or corrosive substances during work on brick closures and coatings.	9
CC-3	Injuries from contact with caustic or corrosive substances during work on concrete foundations and floors.	9
ER-1	Injuries from exposure to radiation due to specific welds.	0
AC-4	Injuries from fires due to specific welds.	0
HV-1	Injuries from being hit or run over by vehicles during material transport operations.	9
HV-2	Injuries from being hit or run over by vehicles during earthworks.	9
HV-3	Injuries from being hit or run over by vehicles during foundation work.	9
HV-4	Injuries from being hit or run over by vehicles in prefabricated structure assembly.	0
TA-1	Injuries from external or internal traffic accidents.	9 / 9
SAFETY RISK LEVEL		**931**
AE-1	Generation of greenhouse gas emissions due to construction machinery and vehicle movements.	15
AE-2	Emission of VOCs and CFCs.	0
WE-1	Dumping of water resulting from the execution of foundations and retaining walls.	0
WE-2	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	**15**
WE-3	Dumping of sanitary water resulting from on-site sanitary conveniences.	3
WG-1	Generation of excavated waste material during earthworks.	9
WG-2	Generation of municipal waste by on-site construction workers.	**15**
WG-3	Generation of inert waste.	**15**
WG-4	Generation of ordinary or non-special waste (wood, plastic, metal, paper, cardboard or glass).	**15**
WG-5	Generation of special (potentially dangerous) waste.	**15**
SA-1	Land occupancy by the building, provisional on-site facilities and storage areas.	9
SA-2	Use of concrete release agent at the construction site.	3
SA-3	Use of cleaning agents or surface-treatment liquids at the construction site.	3
SA-4	Dumping derived from the use and maintenance of construction machinery.	3
SA-5	Dumping of water resulting from the execution of foundations and retaining walls.	0

CONSTRUCTION SAFETY RISK / ENVIRONMENTAL IMPACT		SG
SA-6	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	5
SA-7	Dumping of sanitary water resulting from on-site sanitary conveniences.	3
RC-1	Water consumption during the construction process.	5
RC-2	Electricity consumption during the construction process.	3
RC-3	Fuel consumption during the construction process.	**15**
RC-4	Raw materials consumption during the construction process.	**25**
L-4	Operations that cause dirtiness at the construction site entrances.	**15**
L-6	Landscape alteration by the presence of singular elements (cranes).	3
T-1	Increase in external road traffic due to construction site transport.	3
T-2	Interference in external road traffic due to the construction site.	0
B-1	Operations with vegetation removal (site preparation).	3
B-2	Operations with loss of edaphic soil (site preparation).	3
B-3	Operations with high potential soil erosion (unprotected soils as a consequence of earthworks).	9
B-4	Opening construction site entrances with soil compaction.	0
B-5	Interception of river beds, integration of river beds in the development, water channelling and stream water cutoff.	0
ENVIRONMENTAL IMPACT LEVEL		**212**
L-1	Dust generation in activities with construction machinery and transport.	**15**
L-2	Dust generation in earthworks activities and stockpiles.	**15**
L-3	Dust generation in activities with cutting operations.	**15**
L-5	Generation of noise and vibrations due to site activities.	3
AC-1	Fires at areas for storing flammable and combustible substances.	**15**
AC-2	Breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes).	**15**
AC-3	Breakage of receptacles with harmful substances. Storage tanks for dangerous products.	**15**
ENVIRONMENTAL IMPACT LEVEL / SAFETY RISK LEVEL		**93**

Table 14. Case study 2: overview of the assessment results.

Within the environmental domain, the assessment found that the generation of greenhouse gas emissions due to construction machinery and the movements of vehicles (AE-1) had an extremely significant impact in this construction project. Environmental impact WE-2 (dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids) was also found to be significant. Generation of municipal, inert, non-special and special waste (WG-2, WG-3, WG-4 and WG-5) was also highlighted by the methodology. Environmental impacts RC-3 (fuel consumption during the construction process) and RC-4 (raw

materials consumption during the construction process) were considered significant impacts of this construction project. The last extremely significant environmental impact at this construction project was L-4 (operations that cause dirtiness at the construction site entrances). Detailed assessment results related to this construction project are shown in Table D.16.

The methodology also highlighted some other significant risks that apply to both the environmental and the health and safety domains. This is the case of risks L-1 (dust generation in activities with construction machinery and transport), L-2 (dust generation in earthworks activities and stockpiles) and L-3 (dust generation in activities with cutting operations), which are classified in the environmental category of 'local issues' but also belonging to the safety category of 'contact with chemical agents'. Risks AC-1 (fires at areas for storing flammable and combustible substances), AC-2 (breakage of underground pipes -electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes-) and AC-3 (breakage of receptacles with harmful substances, storage tanks for dangerous products) were also found to be significant. These risks belong to the environmental category of 'accidents and impacts arising, or likely to arise, as consequences of incidents, accidents and potential emergency situations' and to the safety category of 'fires and explosions'. Table D.17 reports detailed results derived from the assessment of common environmental impacts and health and safety risks related to the execution of this construction project.

The methodology has identified the relevance of each environmental aspect and health and safety risk at this particular construction site prior to the construction stage. Therefore, it is possible to implement a range of measures to mitigate them during on-site construction activities. Guidance on this is provided by the ontology-based approach for on-site integrated environmental and health and safety management (Chapter 5).

6.3 Conclusions

This chapter has documented the verification and the validation of the methodology presented in this dissertation and corresponding web-based implementation tool.

In order to verify and validate the methodology, four types of validity were investigated: conceptual methodology validation, data validation, computerized methodology verification and, operational validity. Firstly, conceptual methodology validation was considered to be accomplished given that the developed methodology was accepted to be published in two peer-reviewed journals. Therefore, it can be concluded that the theories and assumptions underlying the conceptual methodology are correct and reasonable. Secondly, data validation ensured that the data necessary

for methodology building, evaluation and testing were adequate and correct. Computerized methodology verification was accomplished by testing the web-based implementation tool, facilitating the verification that the system was operating according to the conceptual methodology and without errors. Finally, operational validation was carried out in order to ensure that the output behaviour of the methodology had sufficient accuracy according to the intended purpose or applicability of the methodology.

The operational validation of any methodology is usually carried out by comparing the output of the methodology resulting from known inputs with facts based on the reality. However, it has been acknowledged that one of the major difficulties in construction research is the lack of test cases upon which research results may be validated. Construction projects are expensive and therefore, testing design alternatives or planning strategies is, in most cases, unfeasible. In the case of non-observable systems, and given that there are no existing methodologies previously validated susceptible to be compared with the developed methodology, existing literature suggests exploring methodology behaviour. In this case, parameter variability-sensitivity analysis was used for operational validation of the developed methodology, changing the values of the input of the methodology to determine the effect upon its output behaviour.

Therefore, this chapter has demonstrated the operational validity of the developed methodology through two different case studies. In the first one, the developed methodology is applied to the design process of a multi-family construction project. The second one focuses on the application of the methodology during the construction planning stage of a single-family house.

On one hand, the application of the methodology in the two case studies demonstrated stability, sensitivity and accuracy. On the other hand, the case studies did not show a significant amount of variability within the outputs of the methodology and therefore no lack of consistency can be attributed to the methodology.

It is also worth highlighting that the case studies also illustrate practical uses of the methodology presented in this dissertation; demonstrating how environmental and health and safety elements can be intrinsically adopted as part of project design, planning and construction.

Chapter 7

Final conclusions

This dissertation has put forth a process-oriented methodology to enhance the integration of environmental and health and safety management systems for construction companies focusing on the sub-systems for identifying, assessing and operationally controlling environmental aspects and health and safety hazards using risk as an integrating factor. This chapter concludes the dissertation with a summary of the main contributions of this research and their possible impact on the field of integrated environmental and health and safety management of construction projects. During the research undertaken, interesting questions were raised although they could not be addressed. They are presented as possible paths to continue research on this field.

7.1 Main contributions

This dissertation presents the state of the art on the implementation of integrated environmental and health and safety management systems in construction companies and its components are highly supported and documented. The main contribution of this body of research is to, for the first time, develop a process-oriented methodology to enhance the integration of environmental and health and safety management systems for construction companies focusing on the sub-systems for identifying, assessing and operationally controlling environmental aspects and health and safety hazards using risk as an integrating factor. Apart from setting the basis for the development of integrated environmental and health and safety management systems in construction companies, the methodology also sets the basis for future studies within this subject area, such as the analysis of the energy

consumption during the whole lifecycle of the building, legislation requirements, etc., just to cite some of the hot spots in current construction management research.

This subsection details an account of the principal findings and implications of this dissertation, demonstrating how the research undertaken has satisfied the objectives initially stated.

The first objective of this thesis was to identify and examine challenges and obstacles encountered by construction organizations during the implementation process and use of environmental management systems (EMSs), occupational health and safety management systems (OHSMSs) and integrated environmental and health and safety management systems. In this sense, Chapter 2 imparts the findings of a literature review carried out to investigate the implementation and use of EMS and OHSMS in construction companies. After determining current application and use of separate EMS and OHSMS in construction companies, it then explores current implementation of integrated environmental and health and safety management systems in construction organizations. Based on a critical review of the related literature, chapter 2 identifies and examines challenges and obstacles encountered by construction organizations during the implementation process and use of integrated environmental and health and safety management systems. The main findings obtained from a critical review of the related literature are:

- In addition to general implementation barriers that may affect all sectors, other authors previously suggested that the inherent peculiarities of the construction industry, such as the large variety of construction techniques and systems, the geographic dispersion of production places and the inherent temporality of the construction projects, may hamper the implementation of EMSs and OHSMSs in construction companies.
- The current MSs structure in contractor's companies tends to be vertical and separate for each system. However, IMSs have been strongly advocated by many researchers to overcome duplicate management tasks. Moreover, it has been demonstrated that certifiable standards (ISO 14001:2004 and OHSAS 18001:2007) allow integration of particular system requirements into a general unified IMS.
- Although a significant lack of case studies on the implementation and use of IMSs in construction companies has been detected, current approaches focus ostensibly on the integration of an EMS or OHSMS with an existing QMS. Therefore, little consideration has been given to the integration of OHSAS 18000 and ISO 14000 or EMAS within construction organisations.
- Integration of MSs is mostly performed as a combination of two or more systems through structural similarities, although the fully integration of all

systems is more desirable. Some previous researchers suggest using risk identification and assessment as an integrating factor.

- Existing literature also highlights that some elements such as structure, size and economic sector may play a decisive role in influencing the breadth or depth of integration of MSs of an organization. In fact, MSs are frequently applied to isolated parts of a construction organization rather than the whole, and therefore its usefulness is questioned.
- The literature review revealed a number of tangible and intangible benefits from integrating different MSs into a single system. Most common obstacles encountered by organizations during the implementation process of an IMS relate to the integration of the elements for identifying hazards/environmental aspects, assess environmental impacts and safety risks and implementing necessary control measures.

The second objective was to identify and examine shortcomings in the current approaches addressing potential on-site environmental impacts and construction worker safety in both the design and construction planning stages. In this sense, Chapter 3 first provides a brief introduction to the environmental and health and safety performance of construction sites. It then provides a critical literature review in relation to the integration of environmental and health and safety aspects during the pre-construction stages, summarizing experiences in both the design and construction planning stages. Finally, chapter 3 identifies and examines the existing shortcomings in current approaches on integrating environmental and health and safety aspects during the pre-construction stages. The main findings of this critical literature review are:

- Most prior construction research has given a limited attention to the on-site construction environmental impacts due to the inherent temporality of the construction stage and a perceived lower significance of construction impacts compared with the lifecycle impacts of building operation. Nevertheless, and according to some research authors, the assumption that the effects of construction are negligible in comparison with the other building phases should only be a supposition because the environmental impacts of construction activities have never been adequately quantified.
- In general, building designers are not legally required to consider potential on-site environmental impacts in their design as residential construction projects are hardly ever subjected to an EIA. Although it has been recognized that proper design in eliminating and/or minimizing environmental hazards for contractors is vital to improved EM, no practical approaches have been found in the existing literature.

- Current approaches to EM during the construction planning stage are limited. Moreover, almost all the methods can be criticised from one or another perspective. Besides the fact that environmental impacts are frequently assessed by the presence or absence of environmental protocols, other methods either summarise too much or not enough information or they either attempt to quantify based on subjective data or remain too qualitative, making the outcome of the process dependent on the people conducting the assessment. In addition, some other methods may be arbitrary and incomplete in their selection of impacts. Contextual issues that relate to site selection and building location are rarely included within the methods.
- Although regulations have imposed an obligation on designers to address safety during the construction phase, they often include generic risk assessments and a simple repository of prevention measures. In addition, the existing literature has not yet addressed the technical principles in order to help designers better perform CHPtD in an interactively way.
- Current legal approaches to planning for health and safety on the construction industry have been criticised for being bureaucratic and irrelevant. Although some authors have addressed construction worker safety in the construction planning stage, their methods keep the subjective nature of hazard identification and risk assessment so its usefulness and effectiveness is hampered.

Research conducted under the first and the second objectives serve as a justification of the research undertaken within this dissertation. In this sense, Chapter 2 has outlined the existing shortcomings of the current approaches which address the implementation of integrated environmental and health and safety management systems in construction companies. The main identified obstacle relates to the integration of the elements for identifying and assessing safety hazards and environmental aspects and implementing necessary control measures. Chapter 3 has identified and examined existing shortcomings in the current approaches on integrating environmental and health and safety aspects during the pre-construction stages.

Thus, Chapter 4 overcomes the existing shortcomings by establishing the necessary basis and criteria to objectively identify and assess environmental and health and safety risks associated with the construction of new residential buildings during the pre-construction stages in line with objective 3 (to identify environmental aspects and health and safety risks related to the construction process with a process-oriented approach) and objective 4 (to assess the environmental aspects and the health and safety risks at the pre-construction stage).

The third objective of this thesis was to identify environmental aspects and health and safety risks related to the construction process with a process-oriented approach (Fig. 37). The key features of the developed methodology are summarized below:

- Instead of providing a standard set of environmental aspects, this methodology proposes an exhaustive preliminary analysis with a process-oriented approach, including a large variety of construction techniques and systems. Therefore, the methodology obtains specific environmental aspects and health and safety risks related to the construction process and tailored to regional specificities. Using this approach, the inclusion of environmental aspects and health and safety risks is neither arbitrary nor incomplete.

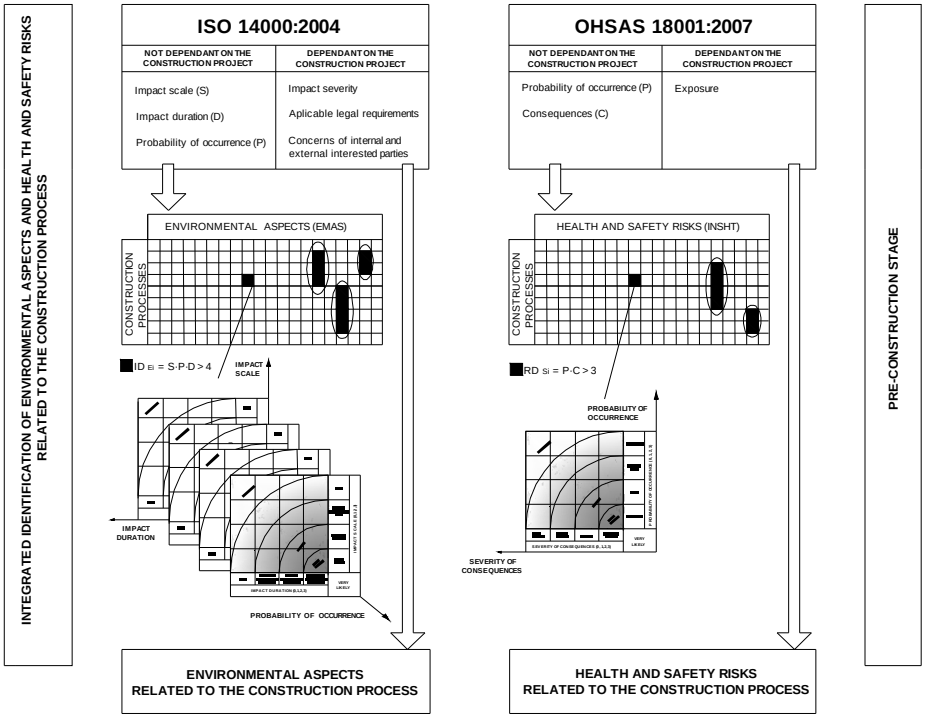


Fig. 37. Overview of the first part of the methodology.

- In addition, the literature often stresses that organizations should not consider the identification of aspects as a single-occasion process. Using the proposed analysis, organizations can add or remove environmental aspects and health and safety risks whenever they want.

- The methodology finally includes 30 environmental aspects and 84 health and safety risks. The developed methodology also includes 7 risks that apply to both the environmental and the health and safety domains.

The fourth objective was to assess the environmental aspects and health and safety risks at the pre-construction stage (Fig. 38). Main contributions in this area are summarized below:

- The assessment of environmental impacts and health and safety risks is particularized for each construction project. In order to objectively assess the environmental impacts' magnitude and the exposure to health and safety risks for a particular construction project, 68 performance indicators, both direct and indirect, have been developed. They are mostly based on quantitative data available in the project documents and thus, the outcome of the process does not depend on the people who conduct it.

- Current performance levels in construction projects were taken as a baseline for assessment. Therefore, significance limits for environmental impacts and health and safety risks were obtained based on the statistical analysis of 55 new-start construction projects.

- Contextual issues that relate to site selection and building location are included within the methodology through the environment parameter, which considers the sensitivity of the location or receptor. The environment parameter is mostly qualitative as there is no available quantitative data in the project documents to assess the interaction between a construction activity and its environment. Therefore, and in order to avoid the intrusion of subjectivity within the method, greater care and precision has been given to the description of the assessment scales.

- A quantitative criterion against which the acceptability of a given environmental impact or health and safety risk is determined. The early identification of environmental impacts and health and safety risks enable designers to start a re-design process; otherwise, it is possible to provide a range of measures for mitigating adverse impacts or risks that can then be implemented during on-site construction activities.

- The methodology also allows obtaining an overall performance score for each construction project alternative. As there is at present neither a consensus-based approach nor a satisfactory method to guide the assignment of weighting, all criteria are assumed to be of equal importance and the overall performance score is obtained by a simple aggregation.

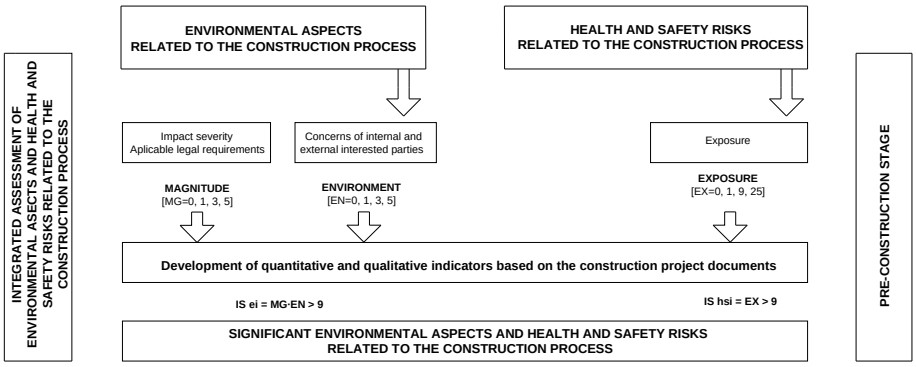


Fig. 38. Overview of the second part of the methodology.

The fifth objective of this thesis was to develop a guidance tool for effective on-site integrated environmental and health and safety management using an ontology-based approach as a technical solution. In this sense, Chapter 5 proposes an effective way of integrating currently separate MSs for environmental and health and safety management in construction companies, contributing to reduce and, if possible, eliminate those obstacles related to a lack of understanding of how best to integrate the different MSs during risk control. The developed ontology-based approach consists of a formal explicit description of concepts (also called classes) in the on-site environmental and health and safety management domain and its properties or relationships. Instances (also called individuals) of each concept can also play an important role in customizing the developed solution in any construction company. The key features of the developed ontology-based approach for on-site integrated environmental and health and safety management are:

- Requirements stated in ISO 14001:2004 and OHSAS 18001:2007 under the subsection of operational control were the basis for defining major classes and its properties within the developed ontology-based approach. Having considered environmental impacts and health and safety risks as central features within this domain, construction processes represented their link

back to their origin whereas work instructions represented the link to action (Fig. 39).

- Since no semantic resources were found to be suitable according to the primary aim of this ontology-driven solution, classes and class hierarchy had to be developed.

    - For the major class 'Construction Processes', this dissertation adopted the work sections provided by ITeC within the MetaBase Database, mainly because it is the most widely used information source including reference prices for work sections in Catalonia since 1985. Therefore, 286 classes, sub-classes and sub-subclasses were taken into account under the major class 'Construction Processes'.

    - A process-oriented approach was used to define classes and class hierarchy for the major classes 'Environmental Impacts' and 'Health and Safety Risks' (see section 4.3). Finally, the major class 'Environmental Impacts' included 46 classes, sub-classes and sub-subclasses and the major class 'Health and Safety Risks' included 116 classes, sub-classes and sub-subclasses.

    - Classes and class hierarchy for the major class 'Work Instructions' were obtained by extracting important concepts from the target domain. After analysing the selected reference documents, a set of 300 concepts emerged.

- Once major classes were defined, the concepts' structure was described by defining four different relationships and its corresponding inverse relations (Fig. 39).

    - The relationship 'takes place in' (and consequently, the relationship 'origins') relates 'Health and Safety Risks' and 'Environmental Impacts' to corresponding 'Construction Processes'. These relationships were obtained analysing 34,606 different situations by means of a process-oriented approach. Finally, 3,314 of them were found to be significant.

    - Relationships 'reduces' (or 'is reduced by'), 'affects positively' (or 'is affected positively'), 'affects negatively' (or 'is affected negatively') relate 'Work Instructions' to corresponding 'Environmental Impacts' or 'Health and Safety Risks'. More than

34,000 relationships relating 'Work Instructions' to 'Environmental Impacts' or 'Health and Safety Risks' were specifically analysed taking into account the purpose of the ontology-based approach for on-site integrated environmental and health and safety management. Finally, 2,791 relationships were found to be significant.

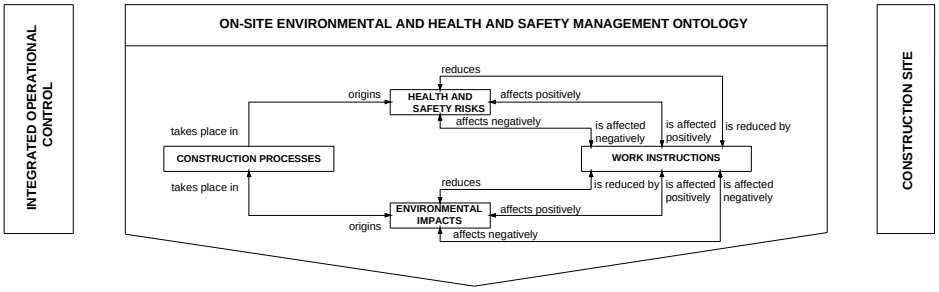


Fig. 39. Overview of the developed ontology-based approach.

Chapters 4 and 5 have detailed a methodology to enhance the integration of environmental and health and safety management systems focusing on the sub-system for identifying, assessing and operationally controlling environmental aspects and health and safety hazards related to the construction process, according to objectives 3, 4 and 5. In order to facilitate a future implementation of the developed methodology in construction companies, a web-based implementation system was developed. The web-based system, together with the implementation of the web-based approach through a radial browser, configures a total automated environmental and health and safety management tool for construction. The major benefits of this IT-tool are summarized below:

- The web-based system allows reducing the time devoted to the assessment of the environmental and the health and safety performance of each construction project. Therefore, the IT-tool enables a speedy way to identify and assess environmental and health and safety risks prior to the construction stage.

- The web-based implementation system also reduces human errors as indicator calculations are performed by the computer.

- The IT-tool facilitates online, automatic, instant graphical presentation of assessment results, facilitating designers and contractors' decision-making process.

- Once significant impacts and risks are identified, the radial browser supports the on-site integrated environmental and health and safety management. The radial browser is able to visualize which work instructions should be planned in order to minimize a particular environmental impact or health and safety risk (taking into account possible interactions between different mitigation measures) and when (in which construction stage) should they be implemented, among others.

Other key features of the developed implementation tool include the removal of geographic barriers as the system access is through an internet domain address. The use of an ordinary web browser eliminates the need for specific hardware or software and it allows sharing detailed information at high speed and at relatively low cost. Obviously, the web-based system also enhances the integration of the environmental and health and safety management in construction projects as a single interface allows assessing the project performance in both domains.

Finally, the sixth objective of this thesis was to verify and validate the developed methodology. In this sense, Chapter 6 focuses on verifying and validating the developed methodology and the corresponding web-based implementation system through investigating conceptual methodology validation, data validation, computerized methodology verification and, operational validity. Conceptual methodology validation ensured that the theories and assumptions underlying the conceptual methodology are correct and reasonable. Data validation ensured that the data necessary for methodology building, evaluation and testing were adequate and correct. Computerized methodology verification was accomplished by testing the web-based implementation system, allowing to make sure the system was operating according to the conceptual methodology and without errors. In order to operationally validate the developed methodology, two different case studies were randomly chosen, each of them focusing on evaluating different aspects of the approach. Besides illustrating practical uses of the methodology presented in this dissertation, case studies also ensured that the model's output behaviour had sufficient accuracy.

The first case study applies the developed methodology to the design process of a multi-family construction project, illustrating how design decisions may entail different environmental and health and safety implications. For example, and according to the methodology, executing an in-situ concrete structure would entail a safety risk level of 108 whereas the safety risk level related to the design of a precast structure was found to be 36. These results are reasonable since on-site activities are

considered to be riskier and less environmentally friendly than those activities that are mainly carried out in more controlled environments. However, the methodology not only does not short the list of significant health and safety risks and environmental impacts but also highlights different environmental impacts and health and safety risks in each case. For example, some health and safety risks such as FS-2 (falls at the same level during reinforcement work) or FOC-2 (injuries from falling objects due to crumble or collapse due to the use of in-situ concrete) among others are found to be significant when designing an in-situ concrete structure but not when designing a precast structure. However, designing a precast structure causes other risks such as FOH-2 (injuries from falling objects during handling in prefabricated structure assembly) or HV-4 (injuries from being hit or run over by vehicles in prefabricated structure assembly). Within the environmental domain, obtained results are also realistic. The environmental impact level of designing an in-situ concrete structure was found to be 41 whereas the environmental impact level of designing a precast structure was to found to be 28. Deigning an in-situ concrete structure significantly reduces environmental impacts SA-2 (use of concrete release agent at the construction site) or RC-1 (water consumption during the construction process), among others. This case study also successfully demonstrates the sensitivity of the developed methodology to the criteria and the predefined scoring system.

The second case study applies the developed methodology to the construction planning stage of a single-family house, identifying the relevance of each environmental aspect and health and safety risk at a particular construction site prior to the construction stage. In this case, 18 health and safety risks, 9 environmental impacts and 6 risks that apply to both the environmental and the health and safety domains were found to be significant. Therefore, and once significant environmental impacts and health and safety risks are identified, it is possible to implement a range of measures to mitigate them during on-site construction activities. Guidance on this is provided by the ontology-based approach for on-site integrated environmental and health and safety management. Several interesting findings from these case studies demonstrate the value of the methodology for practical cases.

The international ISO 14001:2004 and OHSAS 18001:2007 standards are applicable in all countries and the interpretation of their requirements should not be different among the different countries. Hence, although the case studies were limited to construction projects conducted in Spain, the suggested methodology would be applicable to construction projects worldwide with appropriate modification of the environmental and health and safety risks, its indicators and corresponding significance limits.

7.2 Current implications of this research

The aim of this thesis was to develop a process-oriented methodology to enhance the integration of environmental and health and safety management systems for construction companies focusing on the sub-systems for identifying, assessing and operationally controlling environmental aspects and health and safety hazards using risk as an integrating factor. Current implications of the research undertaken within this dissertation are summarized below:

- Establishment of the basis for the development of integrated environmental and health and safety management systems in construction companies.

  It has been argued that the inherent peculiarities related to the construction sector add extra impediments when implementing integrated environmental and health and safety management systems. The approach presented within this thesis overcomes these obstacles by presenting an innovative methodology to integrate planning and control instruments, including elements for identifying and assessing environmental impacts and health and safety risks and implementing subsequent necessary control measures.

- In a parallel way, the proposed methodology can help support the implementation of EMS and OHSMS in construction companies or simply help construction organizations to improve their environmental and safety performance and general decision-making, assuming that the findings of the evaluation are used to make meaningful corrections. Therefore, the proposed methodology serves to three separate roles:

  - Providing an objective assessment of the environmental impacts related to the execution of a construction project and corresponding health and safety implications for construction workers and surrounding population.

  - Providing the basis for making informed design decisions. The large range of current available alternative building materials and construction techniques significantly increases the freedom of the design and consequently the difficulty in finding the most suitable solution. Judgement of the adequacy of a particular building design is frequently related to its appearance, to the way it functions, to its cost or to its execution time. The proposed methodology adds the on-site environmental and health and safety performance axis to the design decision making. In this way, designers can best contribute to improve the environmental and health and safety performance of their designs. Ensuring that an environmentally friendly and a safer design solution is

initially developed during the design phase, saves time and cost in potential incidents or accidents during the construction stage.

- Providing the basis for making informed decisions within contractor's companies. The methodology can offer guidance at all stages during the construction process by highlighting remaining potential environmental impacts and health and safety risks after the design process. Therefore, this method gives useful advices for the construction phase, allowing construction companies to optimize their on-site performance in the environmental and safety domains.

- The methodology provides a consistent basis for comparisons, future labelling and environmental and safety benchmarking between different construction projects and construction companies:
  - Apart from providing an overall picture of the environmental and health and safety on-site performance, the methodology is able to rank the significance of the various environmental impacts and health and safety risks of each assessed construction project or alternative.
  - The methodology allows the comparison of the overall performance profile with that of other construction projects. The methodology is also able to compare the absolute importance of a particular environmental aspect or health and safety risk in various construction projects. In addition, the methodology allows assessing a specific performance criterion relative to a declared benchmark.

The overview of relevant literature in relation to the integration of environmental and health and safety aspects during the pre-construction stages revealed no relevant approaches addressing potential on-site environmental impacts in the design stage. Thus, the methodology presented within this thesis represents a step forward within this subject area. Few studies have been proposed within the subject of integrating aspects of environmental management in the construction planning stage. In my opinion, all of them are arbitrary and incomplete in their section of environmental impacts. For this reason, the developed methodology identifies particularized environmental impacts by means of a process-oriented approach. In contrast to the methodology developed within this dissertation, in some of the existing approaches, construction impacts are assessed by the presence of absence of environmental protocols. Other methods provide qualitative methods with subjective judgements influencing their accuracy. The methodology suggested within this dissertation has developed 68 performance indicators based on data available in the project documents,

most of them quantitative. In case of qualitative indicators, greater care and precision has been given to the description of the assessment scales. Moving to the health and safety domain, the inclusion of health and safety issues during the pre-construction stages is just a consequence of the existing legal requirements. Health and safety studies and plans often include generic risk assessments and therefore, their efficiency and effectiveness are hampered. In more detailed approaches and as well as in the environmental domain, some existing methods include subjective judgements. The methodology presented within this thesis clearly overcomes this situation since health and safety risks are assessed based on quantitative data available within the project documents and therefore risk assessments are particularized to each construction project.

- Formalization of a theoretical framework based on ontology development to enhance the implementation of integrated environmental and health and safety management systems in construction companies through operational control.
- Providing a framework for contractors to effectively manage environmental impacts and health and safety risks during the execution of their construction projects, specially giving support on the implementation of necessary control measures to lower both safety hazards and environmental impacts to an acceptable level.
    - By reviewing the list of work instructions related to a particular environmental impact or health and safety risk, the construction team will be able to identify which on-site work instructions must be implemented in order to either avoid a possible environmental impact or health and safety risk before it occurs or to minimise its negative effect when it does. At the same time, the ontology-based approach for on-site integrated environmental and health and safety management visualizes potential interference between the application of other on-site work instructions and a particular environmental impact or health and safety risk.
    - By reviewing the list of related construction processes where the environmental impact or the health and safety risk may take place, the construction team can identify when corresponding instructions should be implemented.
    - The ontology-based approach is able to visualize which environmental impacts and health and safety risks are related to a particular construction process. Having identified those construction processes with higher significant environmental impacts and health and safety

risks, the developed ontology-based approach can be also used to help the construction companies to plan the inspections' timing and frequency.

- The ontology-based approach for on-site integrated environmental and health and safety management also contributes to clarifying the structure of knowledge related to the integrated on-site environmental and health and safety management and enabling knowledge sharing between not only domain experts but also between the several stakeholders simultaneously involved in a construction site. In this sense, the ontology-based approach for on-site integrated environmental and health and safety management serves two different separate roles:
  - The developed ontology-driven solution provides a starting point by which discussion, communication and decision-making about on-site management can be improved. For example, recording environmental and health and safety incidences using the developed ontology allows construction companies to conduct statistical studies on its environmental and health and safety performance. Such analysis can identify the most frequent activities generating environmental and safety incidences and the most implemented on-site work instructions. This will also assist the project team in learning from the experience of completed projects.
  - The developed solution is also able to contribute to address the existing dichotomy between tacit and explicit knowledge. Any future revision of the ontology-based approach for on-site integrated environmental and health and safety management would allow tacit knowledge to become explicit knowledge, in order to be part of the decision support system.
- This development also demonstrates a practical application of ontologies within the field on on-site integrated environmental and health and safety management.

The suggested methodology was developed relying on the design of the project and subsequent planning decisions to achieve better prevention of environmental impacts and health and safety risks, demonstrating how environmental and health and safety elements can be intrinsically adopted as part of project design, planning and execution. The methodology also enhances the minimization of environmental impacts and health and safety risks through appropriate on-site management. However, the developed methodology is not intended to replace management involvement in making decisions, particularly those involving human factors.

Rather, the methodology wants to improve efficiency and accuracy and should serve as a complement to actual managerial decisions.

7.3 Further research

Some interesting issues were not addressed within this dissertation because they required an analysis beyond the scope of this dissertation. The following is a list of what is considered as the most interesting and urgent research questions seeking for answers and explanations.

- Introduction of a discerned weighting system.
  At this moment, the overall environmental and health and safety performance score of a construction project is obtained by a simple aggregation of all the points awarded to each criterion. Therefore, all criteria are assumed to be of equal importance and all the weighting factors are 1. Future studies should explore the possibility of introducing a weighting system in order to better estimate the overall environmental impact level as well as the overall safety risk level for each construction project alternative. For example, a discerned weighting system should distinguish the importance of death on one side of the spectre to nuisance on the other side.
- Setting up an environmental-safety labelling scheme for construction projects and construction companies.
  Labelling involves the classification of the environmental and safety performance of a construction project or a construction company into descriptive categories (such as fair, good, very good or excellent) or into a numerical scale. Ranges of performance could be obtained by assessing numerous case study construction projects according to the developed methodology.
- Inclusion of contributing causes of accidents within the methodology.
  Immediate causes of accidents include factors that can cause an accident physically and directly, whether the accident happens or not. Among the immediate causes of accidents, unsafe conditions (physical conditions which, if left uncorrected, are likely to cause an accident) and unsafe acts can be distinguished. Unsafe acts are not considered within the methodology because they cannot be assessed during the study, design, planning or preparation stages of a construction project. However, further research needs to be done so that contributing causes of accidents (factors that can further explain immediate accidents, including safety management policy, manager and worker's mental or physical conditions, etc) can be

considered within the methodology. Among the contributing factors, manageable factors for promoting workplace safety performance through reasonable project-safety efforts may also be important when predicting and assessing potential safety risks at the pre-construction stage. A first attempt was made within this dissertation and the safety performance of 25 construction projects was analysed. Unfortunately, no significant correlation was found between the on-site safety performance and manageable factors such the budget devoted to health and safety issues (for both personal and collective protective equipment), the frequency of safety officer's and project manager's presence in construction site, the frequency of external and internal inspections, etc.

- Improvement of the web-based implementation system.
  The time devoted to the assessment of each construction design could be reduced even more if the web-based implementation system allowed importing necessary data from the tools the designer normally uses across the design process. By way of example, all the data related to floor area could be imported automatically from the CAD tool. Other data could be automatically read from the project's Bill of Quantities or the corresponding Health and Safety Plan. This would obviously maximize the usefulness of the developed methodology as a design tool. On the other hand, data collected in previous assessments could be reused in order to refine the methodology, with particular reference to the significance limits of the environmental impacts and health and safety risks.

- Enhancement of future knowledge reuse and shareability.
  In order to enhance future knowledge reuse and shareability, the developed ontology-based approach for on-site integrated environmental and health and safety management should be linked to existing validated ontologies. Given that no taxonomies related to on-site environmental impacts, health and safety risks nor on-site work instructions were found, construction processes should be the link to other existing taxonomies or ontologies within the construction domain. Therefore, a process of semantically relating elements that have the same meaning from different schemas should be carried out. Future mapping could be executed thorough establishing proper 'is similar to' relationships between concepts already included in validated standards related to construction processes and their counterparts in the ontology-based approach for on-site integrated environmental and health and safety management. Although labour-intensive, semantic matching would provide a means of integrating the developed ontology-based approach to other ontologies based in validated standards.

- Extension of the developed methodology to assure continual improvement. The extent to which applicable requirements are being met could be determined by conducting on-site performance monitoring and measurement. However, this requires the definition and acquisition of real performance data related to each significant environmental impact or health and safety risk.

7.4 Final words

Construction is a large, dynamic, and complex industry that plays an important role in meeting the needs of society and enhancing its quality of life. During the last years, occupational fatalities in the construction sector have been disproportionate relative to the number of employees in the business. For this reason, nowadays, health and safety issues configure an explicit and prominent part of most of the arguments used within the construction sector. Similarly, the realities of resource depletion and global environmental degradation have become more evident and current tendencies have pleaded for the inclusion of environmental issues in building construction.

Within this context, the implementation and use of integrated environmental and health and safety management systems in construction projects have the potential to solve one of the most important challenges within the construction sector of our time: to lower the environmental impacts associated with the building construction process while enhancing construction workers' safety. However, integrated environmental and health and safety management systems are fairly complex and unsuitable for construction companies. Therefore, it is necessary to continue developing additional tools and processes in order to assist construction companies, principally when small and medium size enterprises (SMEs) are involved, to implement and use integrated environmental and health and safety management systems.

Finally, this dissertation is an invitation to other researchers in the field to enhance the implementation and use of integrated environmental and health and safety management systems in construction companies, focusing on the on-site measurement of environmental impacts and health and safety risks. This field of research promises to provide deep insight into the environmental and health and safety performance of construction projects and construction sites. Only this kind of understanding could help us to be sure that we are moving forward in our quest to achieve safer, healthy and environmentally sound construction processes.

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Publications

Works carried out into the scope of this thesis, at the examination date, are listed in reversed chronological order:

Journal articles

- Published:

  Gangolells, M., Casals, M., Gassó, S., Forcada, N., Roca, X., Fuertes, A. (2009). A methodology for predicting the severity of environmental impacts related to the construction process of residential buildings. Building and Environment, 44(3), 558-571.

- Accepted:

  Gangolells, M., Casals, M., Forcada, N., Roca, X., Fuertes, A. (In press). Helping professionals better perform Construction Hazards Prevention through Design. Journal of Safety Research.

Articles in conference proceedings

- Published:

  Gangolells M., Casals M., Gassó, S., Forcada N, Roca X, Fuertes, A. (2009) Identifying potential environmental impacts at the pre-construction stage. 3rd CIB International Conference on Smart and Sustainable Built Environments, Delft, Holland.

  Gangolells M, Casals, M, Gassó, S, Forcada, N, Roca, X. (2007). A methodology for predicting the magnitude of environmental impacts related to the building construction process. CIB World Building Conference 2007. Construction for development, Cape Town, South Africa.

- Accepted:

  Gangolells M, Casals, M, Forcada, N, Roca, X., Fuertes, A., Macarulla, M. (2010). Identifying potential safety risks at the design stage. CIB World Congress 2010. Building a better world, Salford, United Kingdom.

Research outcomes were also disseminated to a broader audience through the publication of a press release in Science for Environment Policy[1] promoted by the European Commission, DG Environment. At a national level, research findings were spread through the publication of a press release in Plataforma SINC - Servicio de Información y Noticias Científicas[2] promoted by FECYT-Fundación Española para la Ciencia y la Tecnología (Spanish Science and Technology Foundation), organism under the auspices of the Ministry of Science and Innovation.

Therefore, several European and American internet portals devoted to the dissemination of research news, such as Alpha Galileo[3], promoted by the European Union of Science Journalists' Association, AECC[4], promoted by Asociación Española de Comunicación Científic (Spanish Association of Scientific Communication), Science Centric[5], Science Daily[6] and Redorbit[7] also reported the outcomes of this dissertation.

Apart from the Technical University of Catalonia[8], several official organizations published on its websites information related to the results obtained in this dissertation, such as Portal de las Administraciones Bascas[9] (Basque government website), Unidad de Vigilancia Tecnológica Ecoinnovación[10] (Spanish webpage

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[1] http://ec.europa.eu/environment/integration/research/newsalert/pdf/11si4.pdf (4 February 2009).

[2] http://www.plataformasinc.es/index.php/esl/Noticias/Ya-se-puede-predecir-el-impacto-ambiental-de-la-construccion-de-edificios (2 February 2009).

[3] http://www.alphagalileo.es/ (5 February 2009).

[4] http://www.aecomunicacioncientifica.org/ (2 February 2009).

[5] http://www.sciencecentric.com/ (6 February 2009).

[6] http://www.sciencedaily.com/ (4 February 2009).

[7] http://www.redorbit.com/ (5 February 2009).

[8] http://www.terrassa.upc.edu/ (22 April 2009);
http://www.talent.upc.edu/home/ (29 April 2009).

[9] http://www.euskadi.net/ (13 February 2009).

[10] http://www.uvtcantabria.com/ (4 February 2009).

promoted by the regional environmental ministry of Cantabria and the Cantabrian Chamber of Commerce) and, Osanet[11] (website of the Basque public health system). Research outcomes of this dissertation were also published on the website of the Innovation Committee of the Iranian Ministry of Industries and Mines[12].

Likewise, Spanish professional and business associations also reported on their websites the research results obtained within the framework of this doctoral thesis, such as the ones from CNC – Confederación Nacional de la Construcción [13] (business organization for construction), Fundación Entorno – Consejo Empresarial Español para el Desarrollo Sostenible[14] (Spanish business council for sustainable development), AESMA - Asociación de Empresas del Sector Medioambiental de Andalucía [15] (business organization for environmental industry), Colegio Oficial de Ingenieros Técnicos de Minas de la provincia de Ciudad Real[16] (mining engineers' association) and Sociedad Española de Facility Management [17] (Spanish Society of Facility Management).

Within the construction field, research findings were reported by Deconstrumática, a Spanish journal of architecture, engineering and construction (April 2009). Other construction associations also reported research results related to this dissertation in its websites, such as Construred – Portal de la Construcción [18], Structuralia [19], Construible[20], Concrete online[21], Azo Build[22] and Green Building Talk[23].

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[11] http://www.osanet.euskadi.net/ (13 February 2009).

[12] http://www.icmim.ir/ (19 February 2009).

[13] http://www.formacion.cnc.es/ (10 February 2009).

[14] http://www.fundacionentorno.org/ (5 February 2009).

[15] http://www.aesma.es/ (3 February 2009).

[16] http://www.icoitma.com/ (9 February 2009).

[17] http://sefm.org (3 February 2009).

[18] http://www.construred.com/ (26 February 2009).

[19] http://www.structuralia.com/ (10 February 2009).

[20] http://construible.es/ (10 February 2009).

[21] http://www.concreteonline.com/ (14 February 2009).

[22] http://www.azobuild.com/ (6 February 2009).

[23] http://www.greenbuildingtalk.com/ (10 February 2009).

Several entities related to sustainability and environment also published some reports related to these research findings, such as Fundación Ecología y Desarrollo[24], Portal del Medio Ambiente[25], Ecoticias[26], Environmental Expert[27], Ambientum[28], Global Environment Quality[29], AzoCleanTech[30], Sustentable[31] and Planeta Azul[32].

Several mass media also covered the results obtained during this doctoral thesis, such as COM Radio (13 February 2009), Onda Regional de Murcia (3 February 2009), Onda Madrid (3 February 2009), Radio Prat (13 February 2009) and Terrassa Televisió (23 April 2009). Written press also published reviews on this subject: Diari el Punt (23 April 2009), Diari Avui –Companies Supplement B30 (8 May 2009), Diari de Terrassa (23 April 2009) and Diari ADN (23 April 2009). Nativa monthly magazine from Tandil (Argentina), in its edition on March 2009, also published an interview to disseminate the research findings of this doctoral thesis.

Larger internet portals such as Yahoo[33], Fundación Eroski[34] and Yubanet[35] also contributed to disseminate research outcomes to a broader audience.

[24] http://www.ecodes.org (3 February 2009).

[25] http://portaldelmedioambiente.com/ (5 February 2009).

[26] http://www.ecoticias.com (3 February 2009).

[27] http://www.environmental-expert.com/ (5 February 2009).

[28] http://www.ambientum.com (6 February 2009).

[29] http://www.geq.d/spanish/inicio.php (6 February 2009).

[30] http://www.azocleantech.com (5 February 2009).

[31] http://sustentable.cl (2 March 2009).

[32] http://www.planetaazul.com.mx/ (10 February 2009).

[33] http://es.noticias.yahoo.com (2 February 2009).

[34] http://www.consumer.es/ (3 February 2009).

[35] http://yubanet.com/ (5 February 2009).

Appendix

A. Evaluation of environmental impacts and health and safety risks related to the construction process of a single-family house and a multi-family dwelling

ENVIRONMENTAL ASPECT		INDICATOR [P]	SOURCE		MG[1] = 0	MG = 1	MG = 3	MG= 5
ATMOSPHERIC EMISSIONS								
AE-1	Generation of greenhouse gas emissions due to construction machinery and vehicle movements.	Volume of excavated material per m^2 of floor area $[m^3/m^2] \cdot C + 0.3 \cdot N$; where C=1.2 when special machinery is needed, otherwise C=1.0 and N is the number of power generators.	Bill of quantities / budget / geotechnical study	SF[2]	P[3] = 0.0000	0.0000 < P < 0.3230	0.3230 ≤ P < 2.7601	P ≥ 2.7601
				MF[2]	P = 0.0000	0.0000 < P < 0.6646	0.6646 ≤ P < 1.3454	P ≥ 1.3454
AE-2	Emission of VOCs and CFCs.	% of synthetic paints and varnishes.	Bill of quantities / budget	SF	P = 0.0000	0.0000 < P < 5.1511	5.1511 ≤ P < 43.0626	P ≥ 43.0626
				MF	P = 0.0000	0.0000 < P < 5.1511	5.1511 ≤ P < 43.0626	P ≥ 43.0626
WATER EMISSIONS								
WE-1	Dumping of water resulting from the execution of foundations and retaining walls.	Quantity of thixotropic fluid[4] per m^2 of floor area $[kg/m^2]$.	Bill of quantities / budget	SF	P = 0	-	-	P ≠ 0
				MF	P = 0.0000	0.0000 < P < 2.6335	2.6335 ≤ P < 5.3469	P ≥ 5.3469
WE-2	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	Quantity of in-situ concrete per m^2 of floor area $[m^3/m^2]$.	Bill of quantities / budget	SF	P = 0.0000	0.0000 < P < 0.8891	0.8891 ≤ P <1.1209	P ≥ 1.1209
				MF	P = 0.0000	0.0000 < P < 0.3069	0.3069 ≤ P < 0.5131	P ≥ 0.5131
WE-3	Dumping of sanitary water resulting from on-site sanitary conveniences.	Average number of workers per day.	Health and safety plan	SF	-	0 < P < 6	6 ≤ P < 13	P ≥ 13
				MF	-	0 < P < 13	13 ≤ P < 40	P ≥ 40

ENVIRONMENTAL ASPECT		INDICATOR [P]	SOURCE		MG[1] = 0	MG = 1	MG = 3	MG= 5
WASTE GENERATION								
WG-1	Generation of excavated waste material during earthworks.	Volume of excavated material ending up in landfill sites per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	P = 0.0000	P < 0.2851	0.2851 ≤ P <3.1400	P ≥ 3.1400
				MF	P = 0.0000	P < 0.4299	0.4299 ≤ P <1.3461	P ≥ 1.3461
WG-2	Generation of municipal waste by on-site construction workers.	Average number or workers per day.	Health and safety plan	SF	-	P < 6	6 ≤ P < 13	P ≥ 13
				MF	-	P < 13	13 ≤ P < 40	P ≥ 40
WG-3	Generation of inert waste.	Floor area [m^2].	Building specifications / drawings	SF	-	P < 296.14	296.14 ≤ P < 1,237.37	P ≥ 1,237.37
				MF	-	P < 690.72	690.72 ≤ P < 5,504.27	P ≥ 5,504.27
WG-4	Generation of ordinary or non-special waste (wood, plastic, metal, paper, cardboard or glass).	Floor area [m^2].	Building specifications / drawings	SF	-	P < 296.14	296.14 ≤ P < 1,237.37	P ≥ 1,237.37
				MF	-	P < 690.72	690.72 ≤ P < 5,504.27	P ≥ 5,504.27
WG-5	Generation of special (potentially dangerous) waste.	Floor area [m^2].	Building specifications / drawings	SF	-	P < 296.14	296.14 ≤ P < 1,237.37	P ≥ 1,237.37
				MF	-	P < 690.72	690.70 ≤ P < 5,504.27	P ≥ 5,504.27
SOIL ALTERATION								
SA-1	Land occupancy by the building, provisional on-site facilities and storage areas.	Site occupation per m^2 of floor area [m^2/m^2].	Building specifications / drawings	SF	-	P < 0.5661	0.5661 ≤ P < 2.5532	P ≥ 2.5532
				MF	-	P < 0.1684	0.1684 ≤ P < 0.3376	P ≥ 0.33376

ENVIRONMENTAL ASPECT		INDICATOR [P]	SOURCE		MG[1] = 0	MG = 1	MG = 3	MG= 5
SA-2	Use of concrete release agent at the construction site.	Use of concrete.	Building specifications / drawings	SF	-	Neither the structure of the building nor its facades are made of in-situ concrete.	The structure of the building or most of its facades are made of in-situ concrete.	The structure of the building and most of its facades are made of in-situ concrete.
				MF	-	Neither the structure of the building nor its facades are made of in-situ concrete.	The structure of the building or most of its facades are made of in-situ concrete.	The structure of the building and most of its facades are made of in-situ concrete.
SA-3	Use of cleaning agents or surface-treatment liquids at the construction site.	% of facing brick closure.	Bill of quantities / budget	SF	P = 0.00%	0.00%< P < 14.85%	14.85% ≤ P < 76.51%	P ≥ 76.51%
				MF	P = 0.00%	0.00% < P < 14.85%	14.85% ≤ P < 76.51%	P ≥ 76.51%
		% of the floor area having discontinuous ceramic and/or stone surfaces.	Bill of quantities / budget	SF	P = 0.00%	0.00% < P < 30.33%	30.33% ≤ P < 60.72%	P ≥ 60.72%
				MF	P = 0.00%	0.00% < P < 30.33%	30.33% ≤ P < 60.72%	P ≥ 60.72%
SA-4	Dumping derived from the use and maintenance of construction machinery.	Volume of excavated material per m^2 of floor area [m^3/m^2] + 6E-5·floor area [m^2].	Bill of quantities / budget	SF	-	P < 0.3640	0.3640 ≤ P < 2.7536	P ≥ 2.7536
				MF	-	P < 0.7460	0.7460 ≤ P < 1.8660	P ≥ 1.860
SA-5	Dumping of water resulting from the execution of foundations and retaining walls.	Quantity of thixotropic fluid[4] per m^2 of floor area [kg/m^2].	Bill of quantities / budget	SF	P = 0	-	-	P ≠ 0
				MF	P = 0.0000	0.0000 < P< 2.6335	2.6335 ≤ P < 5.3469	P ≥ 5.3469
SA-6	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	Quantity of concrete per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	P = 0.0000	0.0000 < P < 0.8891	0.8891 ≤ P < 1.1209	P ≥ 1.1209
				MF	P = 0.0000	0.0000 < P< 0.3069	0.3069 ≤ P < 0.5131	P ≥ 0.5131

ENVIRONMENTAL ASPECT		INDICATOR [P]	SOURCE		MG[1] = 0	MG = 1	MG = 3	MG= 5
SA-7	Dumping of sanitary water resulting from on-site sanitary conveniences.	Average number of workers per day.	Health and safety plan	SF	-	$0 < P < 6$	$6 \leq P < 13$	$P \geq 13$
				MF	-	$0 < P < 13$	$13 \leq P < 40$	$P \geq 40$
RESOURCE CONSUMPTION								
RC-1	Water consumption during the construction process.	Water consumption[5] per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	-	$P < 0.0592$	$0.0592 \leq P < 0.1272$	$P \geq 0.1272$
				MF	-	$P < 0.0606$	$0.0606 \leq P < 0.0974$	$P \geq 0.0974$
RC-2	Electricity consumption during the construction process.	Floor area [m^2].	Building specifications / drawings	SF	-	$P < 296.14$	$296.14 \leq P < 1{,}237.37$	$P \geq 1{,}237.37$
				MF	-	$P < 690.72$	$690.72 \leq P < 5{,}504.27$	$P \geq 5{,}504.27$
RC-3	Fuel consumption during the construction process.	Volume of excavated material per m^2 of floor area [m^3/m^2] $\cdot$ C + 0.3·N; where C=1.2 when special machinery is needed, otherwise C=1.0 and N is the number of power generators.	Bill of quantities / budget	SF	$P = 0.0000$	$0.0000 < P < 0.3230$	$0.3230 \leq P < 2.7601$	$P \geq 2.7601$
				MF	$P = 0.0000$	$0.0000 < P < 0.6646$	$0.6646 \leq P < 1.3454$	$P \geq 1.3454$
RC-4	Raw materials consumption during the construction process.	Weight[6] of structural floors, foundations, facades, partition walls, pavements and roofs per m^2 of floor area [kg/m^2].	Bill of quantities / budget	SF	-	$P < 1{,}011.4$	$1{,}011.4 \leq P < 2{,}530.6$	$P \geq 2{,}530.6$
				MF	-	$P < 1{,}095.5$	$1{,}095.5 \leq P < 1{,}642.3$	$P \geq 1{,}642.3$
LOCAL ISSUES								
L-4	Operations that cause dirtiness at the construction site entrances.	Floor area [m^2].	Building specifications / drawings	SF	-	$P < 296.14$	$296.14 \leq P < 1{,}237.37$	$P \geq 1{,}237.37$
				MF	-	$P < 690.72$	$690.72 \leq P < 5{,}504.27$	$P \geq 5{,}504.27$

ENVIRONMENTAL ASPECT		INDICATOR [P]	SOURCE		MG[1] = 0	MG = 1	MG = 3	MG= 5
L-6	Landscape alteration by the presence of singular elements (cranes).	Number of cranes.	Building specifications / bill of quanti-ties / drawings of the health and safety plan	SF	P = 0	-	P < 1	-
				MF	P = 0	P < 2	2 ≤ P < 4	P ≥ 4
TRANSPORT ISSUES								
T-1	Increase in external road traffic due to construction site transport.	Floor area [m^2].	Building specifications / drawings	SF	-	P < 296.14	296.14 ≤ P < 1,237.37	P ≥ 1,237.37
				MF	-	P < 690.72	690.72 ≤ P < 5,504.27	P ≥ 5,504.27
T-2	Interference in external road traffic due to the construction site.	Number of traffic cuts in non-instantaneous periods of time.	Health and safety plan	SF	P = 0	0 < P < 4	4 ≤ P < 15	P ≥ 15
				MF	P = 0	0 < P < 4	4 ≤ P < 15	P ≥ 15
EFFECTS ON BIODIVERSITY								
B-1	Operations with vegetation removal (site preparation).	Site occupation per m^2 of floor area [m^2/m^2].	Building specifications / drawings	SF	-	P < 0.5661	0.5661 ≤ P < 2.5532	P ≥ 2.5532
				MF	-	P < 0.1684	0.1684 ≤ P < 0.3376	P ≥ 0.3376
B-2	Operations with loss of edaphic soil (site preparation).	Site occupation per m^2 of floor area [m^2/m^2].	Building specifications / drawings	SF	-	P < 0.5661	0.5661 ≤ P < 2.5532	P ≥ 2.5532
				MF	-	P < 0.1684	0.1684 ≤ P < 0.3376	P ≥ 0.3376
B-3	Operations with high potential soil erosion (unprotected soils as a consequence of earthworks).	Site occupation per m^2 of floor area [m^2/m^2].	Building specifications / drawings	SF	-	P < 0.5661	0.5661 ≤ P < 2.5532	P ≥ 2.5532
				MF	-	P < 0.1684	0.1684 ≤ P < 0.3376	P ≥ 0.3376

ENVIRONMENTAL ASPECT		INDICATOR [P]	SOURCE		MG[1] = 0	MG = 1	MG = 3	MG= 5
B-4	Opening construction site entrances with soil compaction.	Length of the entrance to the site [m].	Building specifications / drawings	SF	P = 0	P < 500	500 ≤ P < 3,000	P ≥ 3,000
				MF	P = 0	P < 500	500 ≤ P < 3,000	P ≥ 3,000
B-5	Interception of river beds, integration of river beds in the development, water channelling and stream water cutoff.	Number of contact points with river beds.	Drawings / geotechnical study	SF	P = 0	P = 1	P = 2	P > 2
				MF	P = 0	P = 1	P = 2	P > 2

[1] MG: Magnitude of the environmental impact.

[2] SF: Single-family houses.
MF: Multi-family dwellings.

[3] P: Environmental indicator. P values can be extracted from the quantitative data available in the project documents.

[4] Quantity of thixotropic fluid for piles [kg]: $(0.276 \cdot D^2 + 0.242 \cdot D - 0.6413) \cdot L$; where D = piles diameter [cm] and L = piles length [m].
Quantity of thixotropic fluid for screen walls [kg]: $(0.276 \cdot t + 0.7381) \cdot A$, where t = screen wall thickness [cm] and A = total screen wall area [m^2].

[5] Water consumption [m^3] = $0.2 \cdot Ce + 0.6 \cdot G + 0.1 \cdot Co$; where Ce = amount of cement [m^3], G = amount of gypsum [m^3] and Co = amount of concrete [m^3].
Otherwise, water consumption [m^3]= $0.2 \cdot a \cdot Aw + 0.00882 \cdot Ag + 0.1 \cdot Co$; where a = 0.21 in masonry walls, 0.01 in thick partition walls, 0.004 in partition walls, Aw = wall area [m^2], Ag = plastered wall area [m^2] and Co = amount of concrete [m^3].

[6] Weight [kg]: $2{,}500 \cdot Co + 150 \cdot Af + 225 \cdot Aw$; where Co = amount of concrete [m^3], Af = floor area [m^2] and Aw = wall area [m^2].

Table A.1. Evaluation of environmental impacts magnitude related to the construction process of a single-family house (SF) and a multi-family dwelling (MF).

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
FALLS BETWEEN DIFFERENT LEVELS								
FH-1	Falls between different levels during small demolition operations, earthworks and foundation work.	Total perimeter with a difference in floor level of more than 20 cm during the demolition, earthworks or foundation phases per m^2 of site occupation [m/m^2].	Drawings	SF[2]	-	P[3] < 0.4279	0.4279 ≤ P < 1.5269	P ≥ 1.5269
				MF[2]	-	P[2] < 0.4279	0.4279 ≤ P < 1.5269	P ≥ 1.5269
FH-2	Falls between different levels during structural work.	Total perimeter of floors more than 20 cm high (from zero level) plus roof perimeter without boundary walls plus perimeter of holes measuring more than 0.40 m^2 per m^2 of floor area [m/m^2].	Drawings	SF	-	P < 0.0161	0.0161 ≤ P < 1.1715	P ≥ 1.1715
				MF	-	P < 0.0161	0.0161 ≤ P < 1.1715	P ≥ 1.1715
FH-3	Falls between different levels during roof work.	Roof perimeter without boundary walls plus perimeter of holes measuring more than 0.40 m^2 per m^2 of roof area [m/m^2].	Drawings	SF	P = 0.0000	P < 0.3284	0.3284 ≤ P < 0.7213	P ≥ 0.7213
				MF	P = 0.0000	0.0000 < P < 0.2551	0.2551 ≤ P < 0.5809	P ≥ 0.5809
FH-4	Falls between different levels during work on facades, partition walls and vertical coatings.	Total area of partition walls plus total area of cladding on them (parging, plastering, tiling, painting, etc.) [m^2].	Drawings / bill of quantities / budget	SF	-	P< 1,111.1	1,111.1 ≤ P < 2,287.5	P ≥ 2,287.5
				MF	-	P < 3,363.8	3,363.8 ≤ P < 25,216.7	P ≥ 25,216.7
		Total area of facades plus total area of cladding on them (parging, coating, painting, etc.) [m^2].	Drawings / bill of quantities / budget	SF	-	P< 307.94	307.94 ≤ P < 848.47	P ≥ 848.47
				MF	-	P < 480.39	480.39 ≤ P < 5,273.84	P ≥ 5,273.84

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
FH-5	Falls between different levels during floor work.	Total perimeter of holes measuring more than 0.40 m^2 plus total perimeter of balconies without boundary walls per m^2 of floor area [m/m^2].	Bill of quantities / budget	SF	-	P < 0.0414	0.0414 ≤ P < 0.2029	P ≥ 0.2029
				MF	P = 0.0000	0.0000 < P < 0.0708	0.0708 ≤ P < 0.1906	P ≥ 0.1906
FH-6	Falls between different levels during work on door and window closures.	Number of balconies without boundary walls and windows in the building [units].	Bill of quantities / budget	SF	-	P < 4.00	4.00 ≤ P < 18.00	P ≥ 18.00
				MF	-	P < 11.00	11.00 ≤ P < 149.00	P ≥ 149.00
FH-7	Falls between different levels during work on false ceilings and ceiling coatings.	Total area of cladding of structural floors plus total area of false ceilings plus total area of cladding on them (parging, plastering, painting, etc.) [m^2].	Bill of quantities / budget	SF	-	P < 227.55	227.55 ≤ P < 658.67	P ≥ 658.67
				MF	-	P < 462.0	462.0 ≤ P < 6,411.3	P ≥ 6,411.3
FALLS AT THE SAME LEVEL								
FS-1	Falls at the same level during small demolition operations and earthworks.	Site occupation [m^2].	Building specifications / drawings	SF	-	P < 71.76	71.76 ≤ P < 333.17	P ≥ 333.17
				MF	-	P < 114.5	114.5 ≤ P < 1,604.5	P ≥ 1,604.5
FS-2	Falls at the same level during reinforcement work.	Weight of reinforcing bars [kg].	Bill of quantities / budget	SF	-	Prefabricated structures	In-situ concrete structures: P < 8,736.0	In-situ concrete structures: P ≥ 8,736.0
				MF	-	Prefabricated structures	In-situ concrete structures: P < 149,268.9	In-situ concrete structures: P ≥ 149,268.9

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
		Site occupation [m^2].	Building specifications / drawings	SF	-	P < 71.76	71.76 ≤ P < 333.17	P ≥ 333.17
				MF	-	P < 114.5	114.5 ≤ P < 1,604.5	P ≥ 1,604.5
FS-3	Falls at the same level during roof work.	Total area of roof [m^2].	Drawings	SF	-	P < 35.908	35.908 ≤ P < 144.02	P ≥ 144.02
				MF	-	P < 70.064	70.064 ≤ P < 628.140	P ≥ 628.140
FS-4	Falls at the same level during work on partition walls and vertical coatings.	Total area of partition walls plus total area of cladding on them (parging, plastering, tiling, painting, etc.) [m^2].	Drawings / bill of quantities / budget	SF	-	P < 1,111.1	1,111.1 ≤ P < 2,287.5	P ≥ 2,287.5
				MF	-	P < 3,363.8	3,363.8 ≤ P < 25,216.7	P ≥ 25,216.7
FALLING OBJECTS DUE TO CRUMBLE OR COLLAPSE								
FOC-1	Injuries from falling objects due to crumble or collapse during earthworks.	Volume of excavated and/or filled material [m^3].	Bill of quantities / budget	SF	P = 0.00	0.00< P < 76.60	76.605 ≤ P < 851.69	P ≥ 851.69
				MF	P = 0.00	0.00 < P < 203.56	203.56 ≤ P < 12,361.6	P ≥ 12,361.65
FOC-2	Injuries from falling objects due to crumble or collapse due to the use of in-situ concrete.	Volume of in-situ concrete [m^3].	Bill of quantities / budget	SF	P = 0.00	0.00 < P < 75.25	75.25 ≤ P < 313.34	P ≥ 313.34
				MF	P = 0.00	0.00 < P < 154.16	154.16 ≤ P < 2,267.7	P ≥ 2,267.75
FOC-3	Injuries from falling objects due to crumble or collapse during cladding work on facades.	Area of discontinuous cladding in facades [m^2].	Drawings / bill of quantities / budget	SF	P = 0.000	0.00 < P < 17.10	17.10 ≤ P < 275.29	P ≥ 275.29
				MF	P = 0.000	0.000 < P < 22.743	22.743 ≤ P < 320.055	P ≥ 320.055

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
FOC-4	Injuries from falling objects due to crumble or collapse during cladding work on partition walls.	Area of discontinuous cladding in partition walls [m^2].	Drawings / bill of quantities / budget	SF	P = 0,00	0.00 < P < 47.00	47.00 ≤ P < 141.34	P ≥ 141.34
				MF	P = 0.00	0.00 < P < 212.79	212.79 ≤ P < 2,050.08	P ≥ 2,050.1
FOC-5	Injuries from falling objects due to crumble or collapse during false ceiling work.	False ceiling area [m^2].	Drawings / bill of quantities / budget	SF	P = 0.00	0,00 < P < 15.65	15.65 ≤ P < 137.05	P ≥ 137.05
				MF	P = 0.000	0.000 < P < 64.482	64.482 ≤ P < 1,620.3	P ≥ 1,620.336
FALLING OBJECTS DURING HANDLING								
FOH-1	Injuries from falling objects during materials and waste management operations.	Weight[4] of structural floors, foundations, facades, partition walls, floors and roofs [kg].	Bill of quantities / budget	SF	-	P < 310,633	310,633 ≤ P < 977,300	P ≥ 977,300
				MF	-	P < 762,380	762,380 ≤ P < 8,134,735	P ≥ 8,134,735
FOH-2	Injuries from falling objects during handling in prefabricated structure assembly.	In case of prefabricated structures: floor area [m^2].	Bill of quantities / budget	SF	In-situ concrete structures	Prefabricated structures: P < 296.14	Prefabricated structures: 296.14 ≤ P < 1,237.37	Prefabricated structures: P ≥ 1,237.37
				MF	In-situ concrete structures	Prefabricated structures: P < 690.72	Prefabricated structures: 690.72 ≤ P < 5,504.27	Prefabricated structures: P ≥ 5,504.27

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
FOH-3	Injuries from falling objects during handling in cladding work.	Presence of heavy claddings.[5]	Bill of quantities / budget	SF	No heavy claddings.	-	Heavy claddings.	-
				MF	No heavy claddings.	-	Heavy claddings.	-
FOH-4	Injuries from falling objects during handling in work on door and window closures.	Size of window closures [m].	Bill of quantities / budget	SF	-	-	Windows are less than 1 m wide per 1 m of height.	Windows are more than 1 m wide per 1 m of height.
				MF	-	-	Windows are less than 1 m wide per 1 m of height.	Windows are more than 1 m wide per 1 m of height.
OBJECTS FALLING FROM ABOVE								
OF-1	Injuries from objects falling from above during materials and waste management operations.	Weight[4] of structural floors, foundations, facades, partition walls, floors and roofs per m^2 of floor area [kg/m^2].	Bill of quantities / budget	SF	-	P < 1,011.4	1,011.4 ≤ P < 2,530.6	P ≥ 2,530.6
				MF	-	P < 1,095.5	1,095.5 ≤ P < 1,642.3	P ≥ 1,642.3
OF-2	Injuries from objects falling from above during earthworks.	Volume of excavated and/or filled material per m^2 of site occupation [m^3/m^2].	Bill of quantities / budget	SF	P = 0.0000	0.0000 < P < 0,4517	0.4517 ≤ P < 5.6733	P ≥ 5.6733
				MF	P = 0.0000	0.0000 < P < 0.6215	0.6215 ≤ P < 7.1199	P ≥ 7.1199

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
OF-3	Injuries from objects falling from above during structural work.	Volume of in-situ concrete structures per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	-	Prefabricated structures	In-situ concrete structures: P < 0.7284	In-situ concrete structures: P ≥ 0.7284
				MF	-	Prefabricated structures	In-situ concrete structures: P < 0.7284	In-situ concrete structures: P ≥ 0.7284
OF-4	Injuries from objects falling from above during roof work.	Total roof perimeter without boundary walls plus total perimeter of holes in the roof measuring more than 0.40 m^2 per m^2 of roof area [m/m^2].	Drawings	SF	P = 0.0000	P < 0.3284	0.3284 ≤ P < 0.7213	P ≥ 0.7213
				MF	P = 0.0000	0.0000 < P < 0.2551	0.2551 ≤ P < 0.5809	P ≥ 0.5809
OF-5	Injuries from objects falling from above during work on facades and vertical coatings.	Total area of facades plus total area of cladding on them (parging, coating, painting, etc.) [m^2].	Drawings / bill of quantities / budget	SF	-	P < 307,94	307,94 ≤ P < 848,47	P ≥ 848,47
				MF	-	P < 480.39	480.39 ≤ P < 5,273.84	P ≥ 5,273.84
OF-6	Injuries from objects falling from above during work on partition walls and vertical coatings.	Total area of partition walls plus total area of cladding on them (parging, plastering, tiling, painting, etc.) [m^2].	Drawings / bill of quantities / budget	SF	-	P < 1,111.1	1,111.1 ≤ P < 2,287.5	P ≥ 2,287.5
				MF	-	P < 3,363.8	3,363.8 ≤ P < 25,216.7	P ≥ 25,216.7
OF-7	Injuries from objects falling from above during false ceiling work.	False ceiling area [m^2].	Drawings / bill of quantities / budget	SF	P = 0,00	0,00 < P < 15,65	15,65 ≤ P < 137,05	P ≥ 137,05
				MF	P = 0.000	0.000 < P < 64,482	64,482 ≤ P < 1,620.336	P ≥ 1,620.336

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
STEPPING ON OBJECTS								
SO-1	Injuries from stepping on objects during small demolition operations.	Presence of foundations, retaining walls or evacuation elements from previous buildings to be demolished.	Building specifications / bill of quantities / budget	SF	No elements to be demolished.	-	Elements to be demolished.	-
				MF	No elements to be demolished.	-	Elements to be demolished.	-
SO-2	Injuries from stepping on objects during removal of garden elements.	Type of garden elements to be removed.	Building specifications / bill of quantities / budget	SF	No garden elements to be removed.	-	Bushes or short trees (less than 3.5 m tall) to be removed.	Trees (more than 3.5 m tall) to be removed.
				MF	No garden elements to be removed.	-	Bushes or short trees (less than 3.5 m tall) to be removed.	Trees (more than 3.5 m tall) to be removed.
SO-3	Injuries from stepping on reinforcing bars, screws or nails.	In case of wood formwork or unknown type of formwork: volume of in-situ concrete in structures [m^3].	Bill of quantities / budget	SF	P = 0.000	0.000 < P < 21.909	21.909 ≤ P < 148.22	P ≥ 148.223
				MF	P = 0.000	0.000 < P < 73.655	73.655 ≤ P < 1,360.6	P ≥ 1,360.652
		Weight of reinforcing bars [kg].	Bill of quantities / budget	SF	-	Prefabricated structures	In-situ concrete structures: P < 8,736.0	In-situ concrete structures: P ≥ 8,736.0
				MF	-	Prefabricated structures	In-situ concrete structures: P < 149,268.9	In-situ concrete structures: P ≥ 149,268.9

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
HITTING STATIONARY OBJECTS								
HS-1	Injuries from hitting stationary objects in provisional on-site facilities and storage areas.	Site occupation [m^2].	Building specifications / drawings	SF	-	$P < 71.76$	$71.76 \leq P < 333.17$	$P \geq 333.17$
				MF	-	$P < 114.5$	$114.5 \leq P < 1,604.5$	$P \geq 1,604.5$
HS-2	Injuries from hitting stationary objects during small demolition operations.	Presence of foundations, retaining walls or evacuation elements from previous buildings to be demolished.	Building specifications / bill of quantities / budget	SF	No elements to be demolished.	-	Elements to be demolished.	-
				MF	No elements to be demolished.	-	Elements to be demolished.	-
HS-3	Injuries from hitting stationary objects during removal of garden elements.	Type of garden elements to be removed.	Building specifications / bill of quantities / budget	SF	No garden elements to be removed.	-	Bushes or short trees (less than 3.5 m tall) to be removed.	Trees (more than 3.5 m tall) to be removed.
				MF	No garden elements to be removed.	-	Bushes or short trees (less than 3.5 m tall) to be removed.	Trees (more than 3.5 m tall) to be removed.
HS-4	Injuries from hitting stationary objects during structural work.	Volume of in-situ concrete structures per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	-	Prefabricated structures	In-situ concrete structures: $P < 0.7284$	In-situ concrete structures: $P \geq 0.7284$
				MF	-	Prefabricated structures	In-situ concrete structures: $P < 0.7284$	In-situ concrete structures: $P \geq 0.7284$

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
HITTING MOVING OBJECTS								
HM-1	Injuries from hitting moving parts of machinery during materials and waste management operations.	Weight[4] of structural floors, foundations, facades, partition walls, floors and roofs per m^2 of floor area [kg/m^2].	Bill of quantities / budget	SF	-	P < 1,011.4	1,011.4 ≤ P < 2,530.6	P ≥ 2,530.6
				MF	-	P < 1,095.5	1,095.5 ≤ P < 1,642.3	P ≥ 1,642.3
HM-2	Injuries from hitting moving parts of machinery during earthworks.	Volume of excavated and/or filled material per m^2 of site occupation [m^3/m^2].	Bill of quantities / budget	SF	P = 0.0000	0.0000 < P < 0.4517	0.4517 ≤ P < 5.6733	P ≥ 5.6733
				MF	P = 0.0000	0.0000 < P < 0.6215	0.6215 ≤ P < 7.1119	P ≥ 7.1119
HM-3	Injuries from hitting moving parts of machinery during foundation work.	Volume of in-situ concrete in foundations per m^2 of site occupation [m^3/m^2].	Bill of quantities / budget	SF	-	P < 0.2151	0.2151 ≤ P < 1.2226	P ≥ 1.2226
				MF	-	P < 0.2151	0.2151 ≤ P < 1.2226	P ≥ 1.2226
HM-4	Injuries from hitting moving parts of machinery during structural work.	Volume of in-situ concrete structures per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	-	Prefabricated structures	In-situ concrete structures: P < 0.7284	In-situ concrete structures: P ≥ 0.7284
				MF	-	Prefabricated structures	In-situ concrete structures: P < 0.7284	In-situ concrete structures: P ≥ 0.7284
HM-5	Injuries from hitting moving parts of machinery during work on concrete foundations and floors.	Volume of in-situ concrete in concrete foundations and floors per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	-	P < 0.0777	0.0777 ≤ P < 0.2052	P ≥ 0.2052
				MF	-	P < 0.0502	0.0502 ≤ P < 0.1730	P ≥ 0.1730

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
CUTS OR BLOWS FROM OBJECTS AND TOOLS								
CS-1	Injuries from cuts or blows from objects and tools during removal of garden elements.	Type of garden elements to be removed.	Building specifications / bill of quantities / budget	SF	No garden elements to be removed.	-	Bushes or short trees (less than 3.5 m tall) to be removed.	Trees (more than 3.5 m tall) to be removed.
				MF	No garden elements to be removed.	-	Bushes or short trees (less than 3.5 m tall) to be removed.	Trees (more than 3.5 m tall) to be removed.
CS-2	Injuries from cuts or blows from objects and tools during work on foundation and structure.	Volume of in-situ concrete in foundations and structures [m^3].	Bill of quantities / budget	SF	-	Prefabricated structures	In-situ concrete structures: P < 326.60	In-situ concrete structures: P ≥ 326.60
				MF	-	Prefabricated structures	In-situ concrete structures: P < 2,283.95	In-situ concrete structures: P ≥ 2,283.95
CS-3	Injuries from cuts or blows from objects and tools during finishing work on roofs.	Total area of roof [m^2].	Drawings	SF	P = 0.000	0.000 < P < 35.908	35.908 ≤ P < 144.02	P ≥ 144.02
				MF	P = 0.000	0.000 < P < 70.064	70.064 ≤ P < 628.140	P ≥ 628.140
CS-4	Injuries from cuts or blows from objects and tools during work on facades and partition walls.	Total area of facades and partition walls [m^2].	Drawings / bill of quantities / budget	SF	-	P < 366.58	366.58 ≤ P < 1,292.47	P ≥ 1,292.47
				MF	-	P < 874.43	874.43 ≤ P < 10,187.10	P ≥ 10,187.10

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
CS-5	Injuries from cuts or blows from objects and tools during work on coatings or floors.	% of facing brick closure.	Bill of quantities / budget	SF	P = 0.00%	0.00% < P < 14.85%	14.85% ≤ P < 76.51%	P ≥ 76.51%
				MF	P = 0.00%	0.00% < P < 14.85%	14.85% ≤ P < 76.51%	P ≥ 76.51%
		% of area with discontinuous ceramic and/or stone surfaces.	Bill of quantities / budget	SF	P = 0.00%	0.00% < P < 30.33%	30.33% ≤ P < 60.71%	P ≥ 60.71%
				MF	P = 0.00%	0.00% < P < 30.33%	30.33% ≤ P < 60.71%	P ≥ 60.71%
CS-6	Injuries from cuts or blows from objects and tools during work on false ceilings.	False ceiling area [m^2].	Drawings / bill of quantities / budget	SF	P = 0.00	0.00 < P < 15.65	15.65 ≤ P < 137.05	P ≥ 137.05
				MF	P = 0.000	P < 64.482	64.482 ≤ P < 1,620.336	P ≥ 1,620.336
PROJECTION OF FRAGMENTS AND PARTICLES								
FF-1	Injuries from projection of fragments and particles in cutting operations.	% of facing brick closure.	Bill of quantities / budget	SF	P = 0.00%	0.00% < P < 14.85%	14.85% ≤ P < 76.51%	P ≥ 76.51%
				MF	P = 0.00%	0.00% < P < 14.85%	14.85% ≤ P < 76.51%	P ≥ 76.51%
		Total area of ceramic partition walls [m^2].	Bill of quantities / budget	SF	P = 0.0000	0.0000 < P < 149.67	149.67 ≤ P < 802.70	P ≥ 802.70
				MF	P = 0.0000	0.0000 < P < 238.5944	238.5944 ≤ P < 5,202.0000	P ≥ 5,201.9861
		% of area with discontinuous ceramic and/or stone surfaces.	Bill of quantities / budget	SF	P = 0.00%	0.00% < P < 30.33%	30.33% ≤ P < 60.71%	P ≥ 60.71%
				MF	P = 0.00%	0.00% < P < 30.33%	30.33% ≤ P < 60.71%	P ≥ 60.71%
FF-2	Injuries from projection of fragments and particles in concrete operations.	Volume of in-situ concrete in concrete foundations and floors [m^3].	Bill of quantities / budget	SF	-	P < 23.268	23.268 ≤ P < 77.186	P ≥ 77.186
				MF	-	P < 41.207	41.207 ≤ P < 574.129	P ≥ 574.129

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
FF-3	Injuries from projection of fragments and particles in spray-gun painting operations.	% of facade painted with spray gun.	Bill of quantities / budget	SF	P = 0.00%	0.00% < P < 21.64%	21.64% ≤ P < 83.18%	P ≥ 83.18%
				MF	P = 0.00%	0.00% < P < 21.64%	21.64% ≤ P < 83.18%	P ≥ 83.18%
BECOMING CAUGHT IN OR BETWEEN OBJECTS								
CO-1	Injuries from becoming caught in or between objects during materials and waste management operations.	Weight[4] of structural floors, foundations, facades, partition walls, floors and roofs [kg].	Bill of quantities / budget	SF	-	P < 310,633	310,633 ≤ P < 977,300	P ≥ 977,300
				MF	-	P < 762,380	762,380 ≤ P < 8,134,735	P ≥ 8,134,735
CO-2	Injuries from becoming caught in or between objects during small demolition operations.	Presence of foundations, retaining walls or evacuation elements from previous buildings to be demolished.	Building specifications / bill of quantities / budget	SF	No elements to be demolished.	-	Elements to be demolished.	-
				MF	No elements to be demolished.	-	Elements to be demolished.	-
CO-3	Injuries from becoming caught in or between objects during removal of garden elements.	Type of garden elements to be removed.	Building specifications / bill of quantities / budget	SF	No garden elements to be removed.	-	Bushes or short trees (less than 3.5 m tall) to be removed.	Trees (more than 3.5 m tall) to be removed.
				MF	No garden elements to be removed.	-	Bushes or short trees (less than 3.5 m tall) to be removed.	Trees (more than 3.5 m tall) to be removed.
CO-4	Injuries from becoming caught in or between objects during earthworks.	Volume of excavated and/or filled material [m^3].	Bill of quantities / budget	SF	P = 0.00	0.00< P < 76.60	76.60 ≤ P < 851.69	P ≥ 851.69
				MF	P = 0.00	0.00 < P < 203.56	203.56 ≤ P < 12 361.65	P ≥ 12 361.65

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
CO-5	Injuries from becoming caught in or between objects during work on piles, micro-piles and screen walls.	Presence of piles, micro-piles or screen walls.	Bill of quantities / budget	SF	No piles, micro-piles or screen walls.	-	Piles, micro-piles or screen walls.	-
				MF	No piles, micro-piles or screen walls.	-	Piles, micro-piles or screen walls.	
CO-6	Injuries from becoming caught in or between objects in forming and shoring operations.	Volume of in-situ concrete in structure [m^3].	Bill of quantities / budget	SF	P = 0.000	0.000 < P < 21.909	21.909 ≤ P < 148.223	P ≥ 148.223
				MF	P = 0.000	0.000 < P < 73.655	73.655 ≤ P < 1,360.652	P ≥ 1,360.652
CO-7	Injuries from becoming caught in or between objects in operations with scaffoldings or working platforms.	Floor area [m^2].	Building specifications / drawings	SF	-	P < 296.14	296.14 ≤ P < 1237.37	P ≥ 1237.37
				MF	-	P < 690.72	690.72 ≤ P < 5,504.27	P ≥ 5,504.27
BECOMING CAUGHT IN DUMPED VEHICLES OR MACHINES								
CV-1	Injuries from becoming caught in dumped vehicles or machines during materials and waste management operations.	Weight[4] of structural floors, foundations, facades, partition walls, floors and roofs per m^2 of floor area [kg/m^2].	Bill of quantities / budget	SF	-	P < 1,011.4	1,011.4 ≤ P < 2,530.6	P ≥ 2,530.6
				MF	-	P < 1 095.5	1,095.5 ≤ P < 1,642.3	P ≥ 1,642.3

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
CV-2	Injuries from becoming caught in dumped vehicles or machines during earthworks.	Volume of excavated and/or filled material per m^2 of site occupation [m^3/m^2].	Bill of quantities / budget	SF	P = 0.0000	0.0000 < P < 0.4517	0.4517 ≤ P < 5.6733	P ≥ 5.6733
				MF	P = 0.0000	0.0000 < P < 0.6215	0.6215 ≤ P < 7.1199	P ≥ 7.1199
CV-3	Injuries from becoming caught in dumped vehicles or machines during foundation work.	Volume of in-situ concrete in foundations per m^2 of site occupation [m^3/m^2].	Bill of quantities / budget	SF	-	P < 0.2151	0.2151 ≤ P < 1.2226	P ≥ 1.2226
				MF	-	P < 0.2758	0.2758 ≤ P < 1.2045	P ≥ 1.2045
CV-4	Injuries from becoming caught in dumped vehicles or machines during structural work.	Type of auxiliary machinery used to assemble the structure.	Health and safety plan	SF	-	-	Fixed crane	Mobile crane
				MF	-	-	Fixed crane	Mobile crane
CV-5	Injuries from becoming caught in dumped vehicles or machines during pavement work.	Volume of in-situ concrete in concrete foundations and floors per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	-	P < 0.0777	0.0777 ≤ P < 0.2052	P ≥ 0.2052
				MF	-	P < 0.0502	0.0502 ≤ P < 0.1730	P ≥ 0.1730
OVEREXERTION, BAD POSTURE OR REPETITIVE MOTION								
OX-1	Injuries form overexertion, bad posture or repetitive motion.	All cases.	-	SF	-	-	All cases	-
				MF	-	-	All cases	-

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
EXPOSURE TO EXTREME TEMPERATURES								
ET-1	Injuries from exposure to extreme temperatures.	Climate situation of the construction site.	Building specifications	SF	The construction site is not located in an extremely hot or cold climate area.	-	The construction site is located in an extremely hot or cold climate area.	-
				MF	The construction site is not located in an extremely hot or cold climate area.	-	The construction site is located in an extremely hot or cold climate area.	-
THERMAL CONTACTS								
TC-1	Injuries from thermal contacts due to specific welding operations.	Type of structure.	Building specifications	SF	The structure of the building is not metallic.	-	The structure of the building is metallic.	-
				MF	The structure of the building is not metallic.	-	The structure of the building is metallic.	-
TC-2	Injuries from thermal contacts due to joining waterproof membranes.	Type of joints used with waterproof membranes.	Building specifications	SF	Waterproof layer joints are sealed off by mechanical or adhesive means.	-	Waterproof layer joints are sealed off by applying heat.	-

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
				MF	Waterproof layer joints are sealed off by mechanical or adhesive means.	-	Waterproof layer joints are sealed off by applying heat.	-
ELECTRIC CONTACTS								
EC-1	Injuries from electrical contacts with active elements.	All cases.	-	SF	-	-	All cases.	-
				MF	-	-	All cases.	-
EC-2	Injuries from electrical contacts due to breakage of underground electric power cables.	Presence of underground electric power cables.	Building specifications	SF	No underground electric power cables.	-	Underground electric power cables.	-
				MF	No underground electric power cables.	-	Underground electric power cables.	-
EC-3	Injuries from electrical contacts due to contact with balling pumps.	Excavation level.	Building specifications	SF	The excavation level does not exceed the ground-water level.	-	The excavation level exceeds the ground-water level.	-
				MF	The excavation level does not exceed the ground-water level.	-	The excavation level exceeds the ground-water level.	-

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
EC-4	Injuries from electrical contacts due to contacts with overhead electric power lines.	Presence of overhead electric power lines.	Building specifications	SF	No overhead electric power lines.	-	Overhead electric power lines.	-
				MF	No overhead electric power lines.	-	Overhead electric power lines.	-
EXPOSURE TO HARMFUL OR TOXIC SUBSTANCES								
EH-1	Injuries from exposure to harmful or toxic substances during materials and waste management operations.	All cases.	-	SF	-	-	All cases.	-
				MF	-	-	All cases.	-
EH-2	Injuries from exposure to harmful or toxic substances during specific welding operations.	Type of structure.	Building specifications	SF	The structure of the building is not metallic.	-	The structure of the building is metallic.	-
				MF	The structure of the building is not metallic.	-	The structure of the building is metallic.	-

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
EH-3	Injuries from exposure to harmful or toxic substances due to the use of concrete release agents at the construction site.	Use of concrete.	Building specifications / drawings	SF	-	Neither the structure of the building nor its facades are made on in-situ concrete.	The structure of the building (or most of its facades) is made of in-situ concrete.	The structure of the building and most of its facades are made of in-situ concrete.
				MF	-	Neither the structure of the building nor its facades are made on in-situ concrete.	The structure of the building (or most of its facades) is made of in-situ concrete.	The structure of the building and most of its facades are made of in-situ concrete.
EH-4	Injuries from exposure to harmful or toxic substances due to joining waterproof membranes.	Type of joints used with waterproof membranes.	Building specifications	SF	Waterproof layer joints are sealed off by mechanical means.	-	Waterproof layer joints are sealed off by adhesive means or by applying heat.	-
				MF	Waterproof layer joints are sealed off by mechanical means.	-	Waterproof layer joints are sealed off by adhesive means or by applying heat.	-
EH-5	Injuries from exposure to harmful or toxic substances due to the use of synthetic paints and varnishes.	% of synthetic paints and varnishes.	Bill of quantities / budget	SF	P = 0.000%	0.000% < P < 5.151%	5.15% ≤ P < 43.06%	P ≥ 43.063%
				MF	P = 0.000%	0.000% < P < 5.151%	5.15% ≤ P < 43.06%	P ≥ 43.063%

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
EH-6	Injuries from exposure to harmful or toxic substances in surface-polishing operations.	Presence of floor area made from natural wood or other materials that require polishing.	Bill of quantities / budget	SF	No floor area made from natural wood or other materials that require polishing.	-	Floor area made from natural wood or other materials that require polishing.	-
				MF	No floor area made from natural wood or other materials that require polishing.	-	Floor area made from natural wood or other materials that require polishing.	-
CONTACT WITH CAUSTIC OR CORROSIVE SUBSTANCES								
CC-1	Injuries from contact with caustic or corrosive substances during work on foundations and in-situ concrete structures.	Volume of in-situ concrete in foundations and structures [m^3].	Bill of quantities / budget	SF	-	Prefabricated structures	In-situ concrete structures: $P < 2,283.95$	In-situ concrete structures: $P \geq 2,283.95$
				MF	-	Prefabricated structures	In-situ concrete structures: $P < 326.60$	In-situ concrete structures: $P \geq 326.60$
CC-2	Injuries from contact with caustic or corrosive substances during work on brick closures and coatings.	Volume of mortar [m^3].	Bill of quantities / budget	SF	$P = 0.000$	$0.000 < P < 8.03$	$8.03 \leq P < 483.04$	$P \geq 483.04$
				MF	$P = 0.000$	$0.000 < P < 71.248$	$71.248 \leq P < 541.49$	$P \geq 541.495$

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
CC-3	Injuries from contact with caustic or corrosive substances during work on concrete foundations and floors.	Volume of in-situ concrete in concrete foundations and floors [m^3].	Bill of quantities / budget	SF	-	P < 23.268	23.268 ≤ P < 77.186	P ≥ 77.186
				MF	-	P < 41.207	41.207 ≤ P < 574.129	P ≥ 574.129
EXPOSURE TO RADIATION								
ER-1	Injuries from exposure to radiation due to specific welds.	Type of structure.	Building specifications	SF	The structure of the building is not metallic.	-	The structure of the building is metallic.	-
				MF	The structure of the building is not metallic.	-	The structure of the building is metallic.	-
FIRES AND EXPLOSIONS								
AC-4	Injuries from fires due to specific welds.	Type of structure.	Building specifications	SF	The structure of the building is not metallic.	-	The structure of the building is metallic.	-
				MF	The structure of the building is not metallic.	-	The structure of the building is metallic.	-

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
BEING HIT OR RUN OVER BY VEHICLES								
HV-1	Injuries from being hit or run over by vehicles during material transport operations.	Weight[4] of structural floors, foundations, facades, partition walls, floors and roofs per m^2 of site occupation [kg/m^2].	Bill of quantities / budget	SF	-	P < 2,878.33	2,878.33 ≤ P < 9,545.00	P ≥ 9,545.00
				MF	-	P < 2,878.33	2,878.33 ≤ P < 9,545.00	P ≥ 9,545.00
HV-2	Injuries from being hit or run over by vehicles during earthworks.	Volume of excavated and/or filled material per m^2 of site occupation [m^3/m^2].	Bill of quantities / budget	SF	P = 0.0000	0.0000 < P < 0.4517	0.4517 ≤ P < 5.6733	P ≥ 5.6733
				MF	P = 0.0000	0.0000 < P < 0.6215	0.6215 ≤ P < 7.1199	P ≥ 7.1199
HV-3	Injuries from being hit or run over by vehicles during foundation work.	Volume of in-situ concrete in foundations per m^2 of site occupation [m^3/m^2].	Bill of quantities / budget	SF	-	P < 0.2151	0.2151 ≤ P < 1.2226	P ≥ 1.2226
				MF	-	P < 0.2758	0.2758 ≤ P < 1.2045	P ≥ 1.2045
HV-4	Injuries from being hit or run over by vehicles in prefabricated structure assembly.	In case of prefabricated structure: floor area [m^2].	Bill of quantities / budget	SF	In-situ concrete structures	Prefabricated structures: P < 296.14	Prefabricated structures: 296.14 ≤ P < 1,237.37	Prefabricated structures: P ≥ 1,237.37
				MF	In-situ concrete structures	Prefabricated structures: P < 690.72	Prefabricated structures: 690.72 ≤ P < 5,504.27	Prefabricated structures: P ≥ 5,504.27

SAFETY RISK		INDICATOR [P]	SOURCE		EX[1] = 0	EX = 1	EX = 9	EX = 25
TRAFFIC ACCIDENTS								
TA-1	Injuries from external or internal traffic accidents.	Volume of excavated and/or filled material per m^2 of site occupation [m^3/m^2].	Bill of quantities / budget	SF	P = 0.0000	0.0000 < P < 0.4517	0.4517 ≤ P < 5.6733	P ≥ 5.6733
				MF	P = 0.0000	0.0000 < P < 0.6215	0.6215 ≤ P < 7.1199	P ≥ 7.1199
		Weight[4] of structural floors, foundations, facades, partition walls, floors and roofs per m^2 of site occupation [kg/m^2].	Bill of quantities / budget	SF	-	P < 2,878.33	2,878.33 ≤ P < 9,545.00	P ≥ 9,545.00
				MF	-	P < 2,878.33	2,878.33 ≤ P < 9,545.00	P ≥ 9,545.00

[1] EX: risk exposure.

[2] SF: Single-family houses.
MF: Multi-family dwellings.

[3] P: indicator. P values can be extracted from the quantitative data available in the project documents.

[4] Weight [kg]: 2 500·Co + 150·Af + 225·Aw; where Co = amount of concrete [m^3], Af = floor area [m^2] and Aw = wall area [m^2].

[5] Heavy claddings include ceramic and cement mortar tiles, stoneware, limestone, artificial stones and fibrocement sheets.

Table A.2. Evaluation of health and safety risks exposure related to the construction process of a single-family house (SF) and a multi-family dwelling (MF).

ENVIRONMENTAL ASPECT / HEALTH AND SAFETY RISK		INDICATOR [P]	SOURCE		MG/EX = 0	MG/EX = 1	MG/EX = 3	MG/EX = 5
L-1	Dust generation in activities with construction machinery and transport.	Volume of excavated material per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	-	P < 0.2824	0.2824 ≤ P < 2.4987	P ≥ 2.4987
				MF	-	P < 0.5554	0.5554 ≤ P < 1.1686	P ≥ 1.1686
L-2	Dust generation in earthworks activities and stockpiles.	Volume of excavated material per m^2 of floor area [m^3/m^2].	Bill of quantities / budget	SF	-	P < 0.2824	0.2824 ≤ P < 2.4987	P ≥ 2.4987
				MF	-	P < 0.5554	0.5554 ≤ P < 1.1686	P ≥ 1.1686
L-3	Dust generation in activities with cutting operations.	% of facing brick closure.	Bill of quantities / budget	SF	P = 0.00%	0.00% < P < 14.85%	14.85% ≤ P < 76.51%	P ≥ 76.51%
				MF	P = 0.00%	0.00% < P < 14.85%	14.85% ≤ P < 76.51%	P ≥ 76.51%
		% of the floor area having discontinuous ceramic and/or stone surfaces.	Bill of quantities / budget	SF	P = 0.00%	0.00% < P < 30.33%	30.33% ≤ P < 60.72%	P ≥ 60.72%
				MF	P = 0.00%	0.00% < P < 30.33%	30.33% ≤ P < 60.72%	P ≥ 60.72%
L-5	Generation of noise and vibrations due to site activities.	Time of activity, use of special machinery (road roller, graders and compactors, etc.).	Health and safety plan / geotechnical study / budget	SF	-	Normal activity during daytime hours (8:00-20:00) and no use of special machinery.	Normal activity during daytime hours (8:00-20:00) and use of special machinery.	Normal activity during nighttime hours (20:00-8:00).
				MF	-	Normal activity during daytime hours (8:00-20:00) and no use of special machinery.	Normal activity during daytime hours (8:00-20:00) and use of special machinery.	Normal activity during nighttime hours (20:00-8:00).
AC-1	Fires at areas for storing flammable and combustible substances.	Floor area [m^2].	Building specifications / drawings	SF	-	P < 296.14	296.14 ≤ P < 1,237.37	P ≥ 1,237.37
				MF	-	P < 690.72	690.72 ≤ P < 5,504.27	P ≥ 5,504.27

ENVIRONMENTAL ASPECT / HEALTH AND SAFETY RISK		INDICATOR [P]	SOURCE		MG/EX = 0	MG/EX = 1	MG/EX = 3	MG/EX = 5
AC-2	Breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes).	Site occupation per m^2 of floor area [m^2/m^2].	Building specifications / drawings	SF	-	$P < 0.5661$	$0.5661 \leq P < 2.5532$	$P \geq 2.5532$
				MF	-	$P < 0.1684$	$0.1684 \leq P < 0.3376$	$P \geq 0.3376$
AC-3	Breakage of receptacles with harmful substances. Storage tanks for dangerous products.	Floor area [m^2].	Building specifications / drawings	SF	-	$P < 296.14$	$296.14 \leq P < 1,237.37$	$P \geq 1,237.37$
				MF	-	$P < 690.72$	$690.72 \leq P < 5,504.27$	$P \geq 5,504.27$

Table A.3. Evaluation of common environmental aspects magnitude and health and safety risks exposure related to the construction process of a single-family house (SF) and a multi-family dwelling (MF).

ENVIRONMENTAL ASPECT		ENVIRONMENT		
		EN = 1	EN = 3	EN = 5
AE-1	Generation of greenhouse gas emissions due to construction machinery and vehicle movements.	-	-	All cases.
AE-2	Emission of VOCs and CFCs.	-	-	All cases.
WE-1	Dumping of water resulting from the execution of foundations and retaining walls.	Existence of an in-situ waterproof decanting pond or a watertight tank.	Connection to sewage system, dumping in septic tank and/or existence of previous treatment.	Direct dumping to the natural or urban environment.
WE-2	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	Existence of an in-situ waterproof decanting pond or a watertight tank.	Connection to sewage system, dumping in septic tank and/or existence of previous treatment.	Direct dumping to the natural or urban environment.
WE-3	Dumping of sanitary water resulting from on-site sanitary conveniences.	Connection to sewage system.	Dumping in septic tank and/or existence of previous treatment.	Direct dumping to the natural or urban environment.
WG-1	Generation of excavated waste material during earthworks.	In-situ reuse or delivery to an authorized manager for future reuse or recycling.	Delivery to an authorized manager for future disposal or delivery to an authorized manager being unaware of the final waste destination.	On-site waste management unawareness.
WG-2	Generation of municipal waste by on-site construction workers.	In-situ reuse or selective waste collection and delivery to an authorized manager for future reuse or recycling.	Selective waste collection and delivery to an authorized manager for future disposal or delivery to an authorized manager being unaware of the final waste destination.	Non selective waste collection and delivery to an authorized manager or on-site waste management unawareness.
WG-3	Generation of inert waste.	In-situ reuse or selective waste collection and delivery to an authorized manager for future reuse or recycling.	Selective waste collection and delivery to an authorized manager for future disposal or delivery to an authorized manager being unaware of the final waste destination.	Non selective waste collection and delivery to an authorized manager or on-site waste management unawareness.

ENVIRONMENTAL ASPECT		ENVIRONMENT		
		EN = 1	EN = 3	EN = 5
WG-4	Generation of ordinary or non-special waste (wood, plastic, metal, paper, cardboard or glass).	In-situ reuse or selective waste collection and delivery to an authorized manager for future reuse or recycling.	Selective waste collection and delivery to an authorized manager for future disposal or delivery to an authorized manager being unaware of the final waste destination.	Non selective waste collection and delivery to an authorized manager or on-site waste management unawareness.
WG-5	Generation of special (potentially dangerous) waste.	Selective waste collection and delivery to an authorized manager.	-	Non selective waste collection and delivery to an authorized manager or on-site waste management unawareness.
SA-1	Land occupancy by the building, provisional on-site facilities and storage areas.	The affected area is placed inside the construction site perimeter.	The affected area is placed outside the construction site perimeter.	Areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
SA-2	Use of concrete release agent at the construction site.	Urban areas, industrial parks and large waterproofed areas.	Non-protected rural areas away from water courses.	Rural areas near water courses, Areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
SA-3	Use of cleaning agents or surface-treatment liquids at the construction site.	Urban areas, industrial parks and large waterproofed areas.	Non-protected rural areas away from water courses.	Rural areas near water courses, Areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
SA-4	Dumping derived from the use and maintenance of construction machinery.	Urban areas, industrial parks and large waterproofed areas.	Non-protected rural areas away from water courses.	Rural areas near water courses, Areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.

ENVIRONMENTAL ASPECT		ENVIRONMENT		
		EN = 1	EN = 3	EN = 5
SA-5	Dumping of water resulting from the execution of foundations and retaining walls.	Urban areas, industrial parks and large waterproofed areas.	Non-protected rural areas away from water courses.	Rural areas near water courses, areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
SA-6	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	Urban areas, industrial parks and large waterproofed areas.	Non-protected rural areas away from water courses.	Rural areas near water courses, areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
SA-7	Dumping of sanitary water resulting from on-site sanitary conveniences.	Urban areas, industrial parks and large waterproofed areas.	Non-protected rural areas away from water courses.	Rural areas near water courses, areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
RC-1	Water consumption during the construction process.	Use of rainwater or water from the water network.	Use of water from rivers or wells.	Use of water from rivers or wells in drought affected areas.
RC-2	Electricity consumption during the construction process.	Use of electricity from the electricity network.	-	Use of power generators.
RC-3	Fuel consumption during the construction process.	-	-	All cases.
RC-4	Raw materials consumption during the construction process.	Recycled content in raw materials up to 50%.	Recycled content in raw materials ranging from 5 to 50%.	Recycled content raw materials not planned or non-existence of information about it.

ENVIRONMENTAL ASPECT		ENVIRONMENT		
		EN = 1	EN = 3	EN = 5
L-4	Operations that cause dirtiness at the construction site entrances.	Construction site located in low traffic roads.	Construction site located in medium/high traffic roads.	Construction site located in urban area.
L-6	Landscape alteration by the presence of singular elements (cranes).	Urban area without immediate historic-artistic buildings.	Rural areas not registered as an special interest area.	Urban areas with immediate historic-artistic buildings, areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
T-1	Increase in external road traffic due to construction site transport.	Construction site located in low traffic roads.	Construction site located in medium/high traffic roads, where freeway space for vehicle circulation is over 2.75 m in one-way roads, or 6 m in two-way roads.	Construction site located in medium/high density road, where freeway space for vehicle circulation is lower than 2.75 m in-one way roads, or lower than 6 m in two-way roads.
T-2	Interference in external road traffic due to the construction site.	Construction site located in low traffic roads.	-	Construction site located in medium/high traffic roads
B-1	Operations with vegetation removal (site preparation).	The affected area is placed inside the construction site perimeter or the affected area is placed outside the construction site perimeter whenever there is no vegetation.	The affected area is placed outside the construction site perimeter whenever it is filled with vegetation.	Areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
B-2	Operations with loss of edaphic soil (site preparation).	The affected area is placed inside the construction site perimeter or the affected area is placed outside the construction site perimeter whenever there is no edaphic soil.	The affected area is placed outside the construction site perimeter whenever there is still edaphic soil.	Areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.

ENVIRONMENTAL ASPECT		ENVIRONMENT		
		EN = 1	EN = 3	EN = 5
B-3	Operations with high potential soil erosion (unprotected soils as a consequence of earthworks).	The affected area is placed inside the construction site perimeter.	The affected area is placed outside the construction site perimeter.	Areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
B-4	Opening construction site entrances with soil compaction.	The affected area is placed inside the construction site perimeter.	The affected area is placed outside the construction site perimeter.	Areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
B-5	Interception of river beds, integration of river beds in the development, water channelling and stream water cutoff.	Existence of artificial channeling or non-existence of natural river beds.	Natural river beds in non-protected areas.	Natural river beds in areas with legal protection or in other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.

Table A.4. Evaluation of concerns of interested parties of the environmental aspects related to the construction process.

ENVIRONMENTAL ASPECT		ENVIRONMENT		
		EN = 1	EN = 3	EN = 5
L-1	Dust generation in activities with construction machinery and transport.	Distance to a neighboring town center larger than 5,000 m.	Distance to a neighboring town center between 1,000 and 5,000 m.	Construction site located in urban areas or less than 1,000 m from these or in areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
L-2	Dust generation in earthworks activities and stockpiles.	Distance to a neighboring town center larger than 5,000 m.	Distance to a neighboring town center between 1,000 and 5,000 m.	Construction site located in urban areas or less than 1,000 m from these or in areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
L-3	Dust generation in activities with cutting operations.	Distance to a neighboring town center larger than 5,000 m.	Distance to a neighboring town center between 1,000 and 5,000 m.	Construction site located in urban areas or less than 1,000 m from these or in areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.
L-5	Generation of noise and vibrations due to site activities.	Industrial areas or areas affected by acoustic servitude. C or IV-V type zones.	Residential or commercial areas. B or II-III type zones.	High acoustic comfort areas (i. e. urban areas, presence of neighboring, schools, hospitals, areas of special faunistic interest…). A or I type zones.
AC-1	Fires at areas for storing flammable and combustible substances.	Isolated construction site (distance to nearby occupied buildings, forested areas or other high fire risk areas, larger than 500 m).	Distance to nearby occupied buildings, forested areas or other high fire risk areas between 100 and 500 m.	Distance to nearby occupied buildings, forested areas or high fire risk areas lower than 100 m.

ENVIRONMENTAL ASPECT		ENVIRONMENT		
		EN = 1	EN = 3	EN = 5
AC-2	Breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes).	Urban areas with less than 100 inhabitants.	Urban areas with more than 100 inhabitants, whenever the construction site is farther than 500 m from basic services for the community as fire stations, hospitals, airports, power stations, telephones…	Urban areas with more than 100 inhabitants, whenever the construction site is less than 500 m from the basic services for the community as fire stations, hospitals, airports, power stations, telephones…
AC-3	Breakage of receptacles with harmful substances. Storage tanks for dangerous products.	Construction site located in scarce population areas and farther than 100 m from river beds or permeable soils.	Construction site located in scarce population areas and nearer than 100 m from river beds or permeable soils or construction site located in medium population areas.	Construction site located in high density population areas or in areas with legal protection or other areas that, due to its singularity (i.e. natural, archaeological...), must be specially protected.

Table A.5. Evaluation of concerns of interested parties of common environmental aspects and health and safety risks related to the construction process.

Appendix

B. Statistical analysis for quantitative indicators

INDICATOR	SINGLE-FAMILY HOUSES						MULTI-FAMILY DWELLINGS					
	Estimated distribution	Mean	Standard deviation	R^2	Lower limit	Upper limit	Estimated distribution	Mean	Standard deviation	R^2	Lower limit	Upper limit
Volume of excavated material per m^2 of floor area [m^3/m^2] · C + 0.3·N.	Log-normal	-0.025	0.4659	0.9911	0.3230	2.7601	Gaussian	1.005	0.3404	0.9645	0.6646	1.3454
% of synthetic paints and varnishes.	Log-normal	-1.1730	0.4611	0.9843	5.1511	43.0626	Log-normal	-1.173	0.4611	0.9843	5.1511	43.0626
Quantity of concrete per m^2 of floor area [m^3/m^2].	Gaussian	1.005	0.1159	0.9814	0.8891	1.1209	Gaussian	0.410	0.1031	0.9731	0.3069	0.5131
Volume of excavated material ending up in landfill sites per m^2 of floor area [m^3/m^2].	Log-normal	0.025	0.5210	0.9699	0.2851	3.1400	Gaussian	0.888	0.4581	0.9025	0.4299	1.3461
Floor area [m^2].	Log-normal	2.7820	0.3105	0.9690	296.14	1,237.37	Log-normal	3.2900	0.4507	0.9658	690.72	5,504.27
Site occupation per m^2 of floor area [m^2/m^2].	Log-normal	0.080	0.3271	0.9457	0.5661	2.5532	Gaussian	0.253	0.0846	0.9632	0.1684	0.3376
% of facing brick closure.	Gaussian	0.4568	0.3083	0.9389	14.85%	76.51%	Gaussian	0.4568	0.3083	0.9389	14.85%	76.51%
% of the floor area having discontinuous ceramic and/or stone surfaces.	Log-normal	-0.3670	0.1507	0.9546	30.33%	60.72%	Log-normal	-0.3674	0.1507	0.9546	30.33%	60.72%
Volume of excavated material per m^2 of floor area [m^3/m^2] + 6E-5·floor area.	Log-normal	0.0005	0.4394	0.9829	0.3640	2.7536	Gaussian	1.306	0.5600	0.9570	0.7460	1.8660
Water consumption per m^2 of floor area [m^3/m^2].	Gaussian	0.093	0.0340	0.9643	0.0592	0.1272	Gaussian	0.079	0.0184	0.9872	0.0606	0.0974

INDICATOR	SINGLE-FAMILY HOUSES						MULTI-FAMILY DWELLINGS					
	Estimated distribution	Mean	Standard deviation	R^2	Lower limit	Upper limit	Estimated distribution	Mean	Standard deviation	R^2	Lower limit	Upper limit
Weight of structural floors, foundations, facades, partition walls, pavements and roofs per m^2 of floor area [kg/m^2].	Gaussian	1771.0	759.6	0.9362	1011.4	2,530.6	Gaussian	1,368.9	273.4	0.9696	1095.5	1,642.3
Total perimeter with a difference in floor level of more than 20 cm during the demolition, earthworks or foundation phases per m^2 of site occupation area [m/m^2].	Log-normal	-0.0924	0.2763	0.9793	0.4279	1.5269	Log-normal	-0.0924	0.2763	0.9793	0.4279	1.5269
Total perimeter of floors more than 20 cm high (from zero level) plus roof perimeter withour boundary walls plus perimeter of holes measuring more than 0.40 m^2 per m^2 of floor area [m/m^2].	Log-normal	-0.8616	0.9304	0.9749	0.0161	1.1715	Log-normal	-0.8616	0.9304	0.9749	0.0161	1.1715
Roof perimeter without boundary walls plus perimeter of holes measuring more than 0.40 m^2 per m^2 of roof area [m/m^2].	Gaussian	0.5249	0.1964	0.9251	0.3284	0.7213	Gaussian	0.4180	0.1629	0.9545	0.2551	0.5809
Total area of partition walls plus total area of cladding on them (parging, plastering, tiling, painting, etc.) [m^2].	Gaussian	1,699.3	588.24	0.9771	1,111.1	2,287.5	Log-normal	3.9643	0.4374	0.9543	3,363.8	25,216.7
Total area of facades plus total area of cladding on them (parging, coating, painting, etc.) [m^2].	Gaussian	578.22	270.27	0.9732	307.94	848.47	Log-normal	3.2019	0.5203	0.9792	480.39	5,273.8

INDICATOR	SINGLE-FAMILY HOUSES						MULTI-FAMILY DWELLINGS					
	Estimated distribution	Mean	Standard deviation	R^2	Lower limit	Upper limit	Estimated distribution	Mean	Standard deviation	R^2	Lower limit	Upper limit
Total perimeter of holes measuring more than 0.40 m^2 plus total perimeter of balconies without boundary walls per m^2 of floor area [m/m^2].	Log-normal	-1.0378	0.3451	0.9761	0.0414	0.2029	Log-normal	-0.9348	0.2150	0.9706	0.0708	0.1906
Number of balconies and windows in the building [units].	Gaussian	11.403	7.2464	0.9621	4	18	Log-normal	1.5978	0.5744	0.9804	11	149
Total area of cladding of structural floors plus total area of false ceilings plus total area of cladding on them (parging, plastering, tiling, painting, etc.) [m^2].	Log-normal	2.5879	0.2308	0.9789	227.55	658.67	Log-normal	3.2358	0.5712	0.9436	462.00	6,411.3
Site occupation [m^2].	Log-normal	2.1893	0.3334	0.9368	71.765	333.17	Log-normal	2.6321	0.5732	0.9414	114.52	1,604.5
Weight of reinforcing bars [kg].	Log-normal	3.4912	0.4501	0.9564	1,099.5	8,736.0	Log-normal	4.5560	0.6180	0.9501	8,668.7	149,268.9
Total area of roof [m^2].	Gaussian	89.962	54.054	0.9658	35.908	144.02	Log-normal	2.3218	0.4763	0.9736	70.064	628.140
Volume of excavated and/or filled material [m^3].	Log-normal	2.4073	0.5230	0.9415	76.605	851.69	Log-normal	3.2004	0.8917	0.9430	203.56	12,361.6
Volume of in-situ concrete [m^3].	Gaussian	194.30	119.05	0.9483	75.250	313.34	Log-normal	2.7718	0.5838	0.9517	154.16	2,267.7
Area of discontinuous cladding in facades [m^2].	Log-normal	1.8364	0.6034	0.9649	17.103	141.34	Log-normal	1.9310	0.5742	0.9521	22.743	320.055
Area of discontinuous cladding in partition walls [m^2].	Gaussian	94.175	47.170	0.9774	47.005	275.29	Log-normal	2.8199	0.4919	0.9332	212.79	2,050.1
False ceiling area [m^2].	Log-normal	1.6657	0.4712	0.9693	15.65	137.05	Log-normal	2.5095	0.7001	0.9652	64.482	1,620.3

INDICATOR	SINGLE-FAMILY HOUSES						MULTI-FAMILY DWELLINGS					
	Estimated distribution	Mean	Standard deviation	R^2	Lower limit	Upper limit	Estimated distribution	Mean	Standard deviation	R^2	Lower limit	Upper limit
Weight of structural floors, foundations, facades, partition walls, floors and roofs [kg].	Gaussian	643,967	333,333	0.9780	310,633	977,300	Log-normal	6.3963	0.5141	0.9659	762,380	8,134,735
Weight of structural floors, foundations, facades, partition walls, floors and roofs per m^2 of floor area [kg/m^2].	Gaussian	1,771.0	759.00	0.9362	1,011.4	2,530.6	Gaussian	1,368.9	273.4	0.9696	1,095.5	1,642.3
Volume of excavated and/or filled material per m^2 of site occupation [m^3/m^2].	Log-normal	0.2044	0.5495	0.9209	0.4517	5.6733	Log-normal	0.3230	0.5295	0.9306	0.6215	7.1199
Volume of in-situ concrete structures per m^2 of floor area [m^3/m^2].	Gaussian	- 0.5175	0.3798	0.9610	0.1267	0.7284	Gaussian	- 0.5175	0.3798	0.9610	0.1267	0.7284
Volume of in-situ concrete structures [m^3].	Log-normal	1.7558	0.4151	0.9807	21.909	148.22	Log-normal	2.5005	0.6333	0.9645	73.655	1,360.6
Volume of in-situ concrete in foundations per m^2 of site occupation [m^3/m^2].	Log-normal	-0.2900	0.3773	0.9876	0.2151	1.2226	Log-normal	-0.2900	0.3773	0.9876	0.2151	1.2226
Volume of in-situ concrete in concrete foundations and floors per m^2 of floor area [m^3/m^2].	Gaussian	0.1415	0.0638	0.9297	0.0777	0.2052	Gaussian	0.1116	0.0614	0.9006	0.0502	0.1730
Volume of in-situ concrete in foundations and structures [m^3].	Log-normal	2.1577	0.3564	0.9507	63.283	326.60	Log-normal	2.7758	0.5829	0.9711	155.95	2,283.9
Total area of facades and partition walls [m^2].	Log-normal	2.8378	0.2736	0.9726	366.58	1,292.5	Log-normal	3.4749	0.5332	0.9080	874.43	10,187.1

INDICATOR	SINGLE-FAMILY HOUSES						MULTI-FAMILY DWELLINGS					
	Estimated distribution	Mean	Standard deviation	R^2	Lower limit	Upper limit	Estimated distribution	Mean	Standard deviation	R^2	Lower limit	Upper limit
% of facing brick closure.	Gaussian	0.4568	0.3083	0.9389	14.85%	76.51%	Gaussian	0.4568	0.3083	0.9389	14.85%	76.51%
% of area with discontinuous ceramic and/or stone surfaces.	Log-normal	-0.3674	0.1507	0.9546	30.33%	60.71%	Log-normal	-0.3674	0.1507	0.9546	30.33%	60.71%
Total area of ceramic partition walls [m^2].	Log-normal	2.5398	0.3647	0.9317	149.67	802.70	Log-normal	3.0469	0.6693	0.9226	238.59	5,202.0
Volume of in-situ concrete in concrete foundations and floors [m^3].	Log-normal	1.6271	0.2604	0.9917	23.268	77.186	Log-normal	2.1870	0.5720	0.9582	41.207	574.13
% of facade painted with spray gun.	Gaussian	52.406	30.769	0.9642	21.64%	83.18%	Gaussian	52.406	30.769	0.9642	21.64%	83.18%
Volume of mortar [m^3].	Log-normal	1.7943	0.8897	0.9168	8.0284	483.04	Log-normal	2.2932	0.4404	0.9582	71.248	541.49
Weight[3] of structural floors, foundations, facades, partition walls, floors and roofs per m^2 of site occupation [kg/m^2].	Log-normal	6,211.7	3,333.3	0.9731	2,878.3	9,545.0	Log-normal	6,211.7	3,333.3	0.9731	2,878.3	9,545.0
Volume of excavated material per m^2 of floor area [m^3/m^2].	Log-normal	-0.076	0.4734	0.9746	0.2824	2.4987	Gaussian	0.862	0.3066	0.9800	0.5554	1.1686

Table B.1. Statistical analysis for quantitative indicators.

Appendix

C. Defined classes and class hierarchy for the ontology-based approach for on-site integrated environmental and health and safety management

C.1 Construction processes

Materials, equipment and waste management

- Waste classification
- Transportation, unloading and internal movements of materials, equipments and waste

On-site facilities

Demolitions, earthworks and earth management

- Site preparation and earthworks
  - Foundations, retaining walls and evacuation elements
  - Removal of garden elements
  - Basements and underpinning excavations
  - Excavations and review of ditches and wells
  - Earth filling and compacting
  - Filling of ditches and wells
  - Gravel spreading
  - Compacting embankment
- Shoring up
- Soil and inert waste loading and transportation
  - Soil and inert waste transportation
  - Soil and inert waste loading
- Bailing out and reductions on groundwater level
  - Bailing out
  - Reductions on groundwater level
- Earth management
  - Soil supplying
  - Soil transportation to official management centres

Foundations

Formwork, reinforcing and concreting
- Ditches and wells
- Retaining walls
- Braces and butt pillars
- Slab foundations

Piles and micropiles
- Micropiles execution
- Piles drilling and concreting
- Reinforcing piles
- Precast piles

Pile caps
- Pile-caps concreting, reinforcing and formwork

Screen walls
- Screen walls drilling and concreting
- Screen walls reinforcing

Structures

Timber structures
- Pillars, beams, joists, trusses, purlins, wood boards and floorboards

Laminated timber structures
- Pillars, beams, joists, trusses and purlins

Steel structures
- Pillars, anchoring elements, beams, joists, lintels, braces, trusses and purlins

Concrete structures
- Formwork, reinforcing and shuttering of pillars, walls, beams, lintels and straps
- Formwork, reinforcing and shuttering of structural floors with precast resistant elements, unidirectional and bidirectional reinforced concrete slabs

Masonry structures
- Concrete block and ceramic brick walls
- Concrete block and ceramic brick lintels
- Concrete block and ceramic brick straps

- Ceramic brick pillars
- Ceramic brick arches
- Ceramic brick vaults
- Stone masonry structures
  - Stone masonry walls
- Expanded clay brick masonry structures
  - Lightweight expanded clay brick walls
  - Expanded clay brick lintels
- Precast resistant elements for slabs and other structural elements
  - Steel small beams and small vaults
  - Reinforced concrete joists and small vaults
  - Prestressed concrete small beams and small vaults
  - Prestressed concrete foists and vaults
  - Galvanized steel plates for composite slabs
  - Reinforced concrete slabs
  - Alveolar prestressed concrete slabs
  - Ribbed reinforced concrete slabs
  - Ribbed prestressed concrete slabs
  - Precast reinforced concrete pillars
  - Precast reinforced concrete main beams
  - Triangular prestressed precast concrete main beams
  - Triangular reinforced precast concrete main beams
  - Precast reinforced concrete staircases
  - Precast reinforced concrete terraces

Roofs

- Flat roofs
- Tile roofs
  - Ceramic tiles
  - Mortar tiles
  - Slate tiles
  - Roof windows
- Sheet roofs

- Fibrocement sheets
- Reinforced polyester sheets
- Steel sheets with slope less than 30%

Metal sheet roofs

- Zinc sheets
- Copper sheets
- Steel sheets with slope less than 30%
- Steel sheets with slope more than 30%
- Deck

Roof lights

Partitions and closures

Masonry walls, partition walls and thick partition walls

- Ceramic brick walls and partition walls
- Mortar block walls
- Expanded clay mortar block walls
- Cellular concrete block walls
- Molded glass walls
- Plaster partition walls

Sheet closures

- Fibrocement sheets
- Reinforced polyester sheets
- Steel sheets
- Aluminium panels for facades
- Precast, lightened or ribbed reinforced concrete slabs
- Metal sheets
- Metal frames for plasterboard walls

Dividing screens

- Fixed steel frames
- Fixed anodised aluminium frames
- Fixed lacquered aluminium frames

Curtain wall elements

- Aluminium frames for curtain walls

Waterproofing and insulation

- Unprotected bituminous sheet membranes
  - Unprotected bituminous adherent sheet membranes
  - Unprotected bituminous non-adherent sheet membranes
- Bituminous sheet membranes with mineral autoprotection
  - Bituminous adhered sheet membranes with mineral autoprotection
  - Bituminous semi-adhered sheet membranes with mineral autoprotection
- Bituminous sheet membranes with metal autoprotection
  - Bituminous adhered sheet membranes with metal autoprotection
  - Bituminous semi-adhered sheet membranes with metal autoprotection
- Unprotected PVC sheet membranes
  - Unprotected PVC adhered sheet membranes
  - Unprotected PVC non-adhered sheet membranes
- Autoprotected PVC sheet membranes
  - Autoprotected PVC adhered sheet membranes
  - Autoprotected PVC non-adhered sheet membranes
  - Autoprotected PVC fixed sheet membranes
- Elastomeric sheet membranes
  - Elastomeric adhered sheet membranes
  - Elastomeric semi-adhered sheet membranes
  - Elastomeric non-adhered sheet membranes
  - Elastomeric fixed sheet membranes
- Polyethylene and polyolefin sheet membranes
  - Polyethylene and polyolefin fixed sheet membranes
  - Polyethylene and polyolefin non-adhered sheet membranes
- Waterproofing with amorphous products
  - Elastomeric pastes
  - Acrylic polymers
- Waterproofing with panels and drainage sheets
  - Drained polyethylene relief sheets
- Watertight barriers
  - Bituminous

- Synthetic
- Metal

Thermal, acoustic and sound-absorbing insulations

- Amorphous
- Polystyrene boards
- Polyurethane boards
- Glass wool boards
- Cork boards
- Cellular glass boards
- Polyethylene sheets, boards and slabs
- Rock wool boards
- Expanded perlite boards
- Expanded polystyrene boards ready for supporting continuous amorphous coatings
- Felts and polyester panels
- Sandwich panels

Fire-resistant insulations

- Perlite mortars
- Intumescent fire-resistant paints
- Silicate boards
- Silicate false ceiling boards

Coatings

Parging and plastering

- Parging
- Plastering

Tilling

- Natural ceramic tilling
- Refractory ceramic tilling
- Glazed tilling
- Brilliant glazed ceramic tilling
- Matt glazed ceramic tilling
- Glazed ceramic tilling
- Unglazed stoneware tilling

- Glazed stoneware tilling
- Porcelain stoneware tilling
- Pressed glazed stoneware tilling
- Ceramic veneering
- Cement mortar veneering

Veneering
- Artificial stone veneering
- Stoneware stone veneering
- Limestone stone veneering
- Granite stone veneering
- Laminated plasterboard veneering
- Fiberboard veneering
- Synthetic board veneering
- Fibrocement board veneering
- Aluminium panel veneering

False ceilings
- Plasterboard false ceilings
- Mineral or vegetal fiberboard false ceilings
- Laminated plasterboard false ceilings
- Wooden board false ceilings
- Metal slats or board false ceilings
- PVC slat false ceilings

Decorative coatings
- Wood decorative coatings
- Cork decorative coatings
- Synthetic decorative coatings
- Stainless steel board decorative coatings
- Aluminium board decorative coatings

Stuccoworks, sgraffitos and painted elements
- Stuccoworks, sgraffitos and single layer coatings
- Structures, faces and closure elements painting
- Pipes and heating and protection elements painting

Varnished elements

- Structures, faces and closure elements varnishing
- Heating and protection elements varnishing

Pavements

- Subbases
  - Subbases
  - Aggregate subbases
  - Expanded clay subbases
- Bases and screeds
  - Concrete or lightweight concrete bases
  - Lightened concrete bases
  - Screeds
- Inside technical pavements
- Natural stone pavements, skirting and steps
  - Stoneware pavements, skirting and steps
  - Limestone pavements, skirting and steps
  - Granitic pavements, skirting and steps
- Artificial stone pavements, skirting and steps
  - Smooth terrazzo pavements, skirting and steps
  - Relief terrazzo pavements, skirting and steps
  - Acid wash terrazzo pavements, skirting and steps
  - Terrazzo upon supports pavements, skirting and steps
  - Continuous terrazzo pavements, skirting and steps
- Ceramic and stoneware tile pavements, skirting and steps
  - Natural ceramic tile pavements, skirting and steps
  - Unglazed stoneware tile pavements, skirting and steps
  - Glazed stoneware tile pavements, skirting and steps
  - Porcelain stoneware tile pavements, skirting and steps
  - Pressed and glazed stoneware tile pavements, skirting and steps
  - Ceramic cobblestones pavements, skirting and steps
- Concrete pavements
  - Finishes without additives
  - Finishes with additives

- Light
- Cork slabs pavements
- Synthetic pavements skirting boards
  - PVC synthetic pavements and skirting boards
  - Rubber
- Wood pavements, skirting and steps
  - Adhered parquet pavements, skirting boards and steps
  - Nailed parquet pavements, skirting boards and steps
  - Wood finishes floating parquet pavements, skirting boards and steps
  - Synthetic finishes floating parquet pavements, skirting boards and steps
- Textile pavements
  - Wool fitted carpets
  - Synthetic fitted carpets
- Metallic board and lattice pavements, skirting boards and steps
- Special elements for pavements
  - Pavements, tapering and polishing
  - Painting and varnishing of pavements

Door and window closures

- Wood door and window closures
  - Oak for varnishing
  - African teak for varnishing
  - Southern pine for varnishing
  - Scots pine for painting
- Laminated steel door and window closures
  - Laminated steel doors
- Aluminium door and window closures
- PVC door and window closures
- Glass door and window closures
- Commercial, industrial and common use doors
  - Swinging, rolling, pivoted, fast or sectional doors
- Fire doors
- Acoustic doors

Blinds
- Wood blinds
- Steel blinds
- Aluminium blinds
- PVC blinds
- Textile blinds

C.2 Environmental impacts

Atmospheric emissions

AE-1: Generation of greenhouse gas emissions due to construction machinery and vehicle movements.

AE-2: Emission of VOCs and CFCs.

Water emissions

WE-1: Dumping of water resulting from the execution of foundations and retaining walls.

WE-2: Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.

WE-3: Dumping of sanitary water resulting from on-site sanitary conveniences.

Waste generation

WG-1: Generation of excavated waste material during earthworks.

WG-2: Generation of municipal waste by on-site construction workers.

WG-3: Generation of inert waste.

WG-4: Generation of ordinary or non-special waste (wood, plastic, metal, paper, cardboard or glass).

WG-5: Generation of special (potentially dangerous) waste.

Soil alteration

SA-1: Land occupancy by the building, provisional on-site facilities and storage areas.

SA-2: Use of concrete release agent at the construction site.

SA-3: Use of cleaning agents or surface-treatment liquids at the construction site.

SA-4: Dumping derived from the use and maintenance of construction machinery.

SA-5: Dumping of water resulting from the execution of foundations and retaining walls.

SA-6: Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.

SA-7: Dumping of sanitary water resulting from on-site sanitary conveniences.

Resource consumption

RC-1: Water consumption during the construction process.

RC-2: Electricity consumption during the construction process.

RC-3: Fuel consumption during the construction process.

RC-4: Raw materials consumption during the construction process.

Local issues

L-1: Dust generation in activities with construction machinery and transport.

L-2: Dust generation in earthworks activities and stockpiles.

L-3: Dust generation in activities with cutting operations.

L-4: Operations that cause dirtiness at the construction site entrances.

L-5: Generation of noise and vibrations due to site activities.

L-6: Landscape alteration by the presence of singular elements (cranes).

Transport issues

T-1: Increase in external road traffic due to construction site transport.

T-2: Interference in external road traffic due to the construction site.

Effects on biodiversity

B-1: Operations with vegetation removal (site preparation).

B-2: Operations with loss of edaphic soil (site preparation).

B-3: Operations with high potential soil erosion (unprotected soils as a consequence of earthworks).

B-4: Opening construction site entrances with soil compaction.

B-5: Interception of river beds, integration of river beds in the development, water channelling and stream water cutoff.

Incidents, accidents and potential emergency situations

AC-1: Fires at areas for storing flammable and combustible substances.

AC-2: Breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes).

AC-3: Breakage of receptacles with harmful substances. Storage tanks for dangerous products.

C.3 Health and safety risks

Falls between different levels

FH-1: Falls between different levels during small demolition operations, earthworks and foundation work.

FH-2: Falls between different levels during structural work.

FH-3: Falls between different levels during roof work.

FH-4: Falls between different levels during work on facades, partition walls and vertical coatings.

FH-5: Falls between different levels during floor work.

FH-6: Falls between different levels during work on door and window closures.

FH-7: Falls between different levels during work on false ceilings and ceiling coatings.

Falls at the same level

FS-1: Falls at the same level during small demolition operations and earthworks.

FS-2: Falls at the same level during reinforcement work.

FS-3: Falls at the same level during roof work.

FS-4: Falls at the same level during work on partition walls and vertical coatings.

Falling objects due to crumble or collapse

FOC-1: Injuries from falling objects due to crumble or collapse during earthworks.

FOC-2: Injuries from falling objects due to crumble or collapse due to the use of in-situ concrete.

FOC-3: Injuries from falling objects due to crumble or collapse during cladding work on facades.

FOC-4: Injuries from falling objects due to crumble or collapse during cladding work on partition walls.

FOC-5: Injuries from falling objects due to crumble or collapse during false ceiling work.

Falling objects during handling

FOH-1: Injuries from falling objects during materials and waste management operations.

FOH-2: Injuries from falling objects during handling in prefabricated structure assembly.

FOH-3: Injuries from falling objects during handling in cladding work.

FOH-4: Injuries from falling objects during handling in work on door and window closures.

Objects falling from above

OF-1: Injuries from objects falling from above during materials and waste management operations.

OF-2: Injuries from objects falling from above during earthworks.

OF-3: Injuries from objects falling from above during structural work.

OF-4: Injuries from objects falling from above during roof work.

OF-5: Injuries from objects falling from above during work on facades and vertical coatings.

OF-6: Injuries from objects falling from above during work on partition walls and vertical coatings.

OF-7: Injuries from objects falling from above during false ceiling work.

Stepping on objects

SO-1: Injuries from stepping on objects during small demolition operations.

SO-2: Injuries from stepping on objects during removal of garden elements.

SO-3: Injuries from stepping on reinforcing bars, screws or nails.

Hitting stationary objects

HS-1: Injuries from hitting stationary objects in provisional on-site facilities and storage areas.

HS-2: Injuries from hitting stationary objects during small demolition operations.

HS-3: Injuries from hitting stationary objects during removal of garden elements.

HS-4: Injuries from hitting stationary objects during structural work.

Hitting moving objects

HM-1: Injuries from hitting moving parts of machinery during materials and waste management operations.

HM-2: Injuries from hitting moving parts of machinery during earthworks.

HM-3: Injuries from hitting moving parts of machinery during foundation work.

HM-4: Injuries from hitting moving parts of machinery during structural work.

HM-5: Injuries from hitting moving parts of machinery during work on concrete foundations and floors.

Cuts or blows from objects and tools

CS-1: Injuries from cuts or blows from objects and tools during removal of garden elements.

CS-2: Injuries from cuts or blows from objects and tools during work on foundation and structure.

CS-3: Injuries from cuts or blows from objects and tools during finishing work on roofs.

CS-4: Injuries from cuts or blows from objects and tools during work on facades and partition walls.

CS-5: Injuries from cuts or blows from objects and tools during work on coatings or floors.

CS-6: Injuries from cuts or blows from objects and tools during work on false ceilings.

Projection of fragments and particles

FF-1: Injuries from projection of fragments and particles in cutting operations.

FF-2: Injuries from projection of fragments and particles in concrete operations.

FF-3: Injuries from projection of fragments and particles in spray-gun painting operations.

Becoming caught in or between objects

CO-1: Injuries from becoming caught in or between objects during materials and waste management operations.

CO-2: Injuries from becoming caught in or between objects during small demolition operations.

CO-3: Injuries from becoming caught in or between objects during removal of garden elements.

CO-4: Injuries from becoming caught in or between objects during earthworks.

CO-5: Injuries from becoming caught in or between objects during work on piles, micro-piles and screen walls.

CO-6: Injuries from becoming caught in or between objects in forming and shoring operations.

CO-7: Injuries from becoming caught in or between objects in operations with scaffoldings or working platforms.

Becoming caught in dumped vehicles or machines

CV-1: Injuries from becoming caught in dumped vehicles or machines during materials and waste management operations.

CV-2: Injuries from becoming caught in dumped vehicles or machines during earthworks.

CV-3: Injuries from becoming caught in dumped vehicles or machines during foundation work.

CV-4: Injuries from becoming caught in dumped vehicles or machines during structural work.

CV-5: Injuries from becoming caught in dumped vehicles or machines during structural work.

Overexertion, bad posture or repetitive motion

OX-1: Injuries form overexertion, bad posture or repetitive motion.

Exposure to extreme temperatures

ET-1: Injuries from exposure to extreme temperatures.

Thermal contacts

TC-1: Injuries from thermal contacts due to specific welding operations.

TC-2: Injuries from thermal contacts due to joining waterproof membranes.

Electric contacts

EC-1: Injuries from electrical contacts with active elements.

EC-2: Injuries from electrical contacts due to breakage of underground electric power cables.

EC-3: Injuries from electrical contacts due to contact with balling pumps.

EC-4: Injuries from electrical contacts due to contacts with overhead electric power lines.

Exposure to harmful or toxic substances

EH-1: Injuries from exposure to harmful or toxic substances during materials and waste management operations.

EH-2: Injuries from exposure to harmful or toxic substances during specific welding operations.

EH-3: Injuries from exposure to harmful or toxic substances due to the use of concrete release agents at the construction site.

EH-3: Injuries from exposure to harmful or toxic substances due to the use of concrete release agents at the construction site.

EH-4: Injuries from exposure to harmful or toxic substances due to joining waterproof membranes.

EH-5: Injuries from exposure to harmful or toxic substances due to the use of synthetic paints and varnishes.

EH-6: Injuries from exposure to harmful or toxic substances in surface-polishing operations.

Contact with caustic or corrosive substances

CC-1: Injuries from contact with caustic or corrosive substances during work on foundations and in-situ concrete structures.

CC-2: Injuries from contact with caustic or corrosive substances during work on brick closures and coatings.

CC-3: Injuries from contact with caustic or corrosive substances during work on concrete foundations and floors.

Exposure to radiation

ER-1: Injuries from exposure to radiation due to specific welds.

Fires and explosions

AC-1: Fires at areas for storing flammable and combustible substances.

AC-2: Breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes).

AC-3: Breakage of receptacles with harmful substances. Storage tanks for dangerous products.

AC-4: Injuries from fires due to specific welds.

Contact with chemical agents

L-1: Dust generation in activities with construction machinery and transport.

L-2: Dust generation in earthworks activities and stockpiles.

L-3: Dust generation in activities with cutting operations.

Being hit or run over by vehicles

HV-1: Injuries from being hit or run over by vehicles during material transport operations.

HV-2: Injuries from being hit or run over by vehicles during earthworks.

HV-3: Injuries from being hit or run over by vehicles during foundation work.

HV-4: Injuries from being hit or run over by vehicles in prefabricated structure assembly.

Traffic accidents

TA-1: Injuries from external or internal traffic accidents.

Contact with physical agents

L-5: Generation of noise and vibrations due to site activities.

C.4 Work instructions

Instructions for using personal protection equipment

Instructions for using harnesses.
Instructions for using ear protection headphones or hearing protections.
Instructions for using protective footwear.
Instructions for using waterproof protective footwear.
Instructions for using non-slip protective footwear.
Instructions for using hard hats.
Instructions for using antivibration belts.
Instructions for using protective aprons against mechanical hazards.
Instructions for using back belts.
Instructions for using particle protection goggles.
Instructions for using sungoggles.
Instructions for using safety goggles.
Instructions for using protective gloves against mechanical hazards.
Instructions for using protective gloves against chemical hazards.
Instructions for using protective gloves against thermal hazards.
Instructions for using protective gloves against electrical hazards.
Instructions for using protective gloves against extreme temperatures.
Instructions for using waterproof gloves.
Instructions for using handles and protective mittens.
Instructions for using protective masks and face masks.
Instructions for using protective face shields.
Instructions for using protective gaiters.
Instructions for using work clothing.
Instructions for using waterproof work clothing.
Instructions for using tight work clothing.
Instructions for using fire-resistant work clothing.
Instructions for using cold weather work clothing.
Instructions for using high visibility work clothing.

Instructions for using collective protection equipment

Instructions for placing scaffolds.

Instructions for placing perimeter scaffolds.

Instructions for placing mechanical vibrations attenuator seats and platforms.

Instructions for placing reflective bands.

Instructions for placing resistant guard rails.

Instructions for placing New Jersey barriers.

Instructions for placing rebar protective caps.

Instructions for placing insulator and shock absorber elements in tools and equipments.

Instructions for placing heaters to recover and/or protect from cold weather.

Instructions for placing anchored lifelines.

Instructions for placing plastic safety meshes.

Instructions for placing electrowelded wiremeshes.

Instructions for placing metallic screens.

Instructions for placing horizontal fireproof blankets.

Instructions for placing marquees.

Instructions for placing modular acoustic screens.

Instructions for placing catwalks.

Instructions for placing fixed and mobile work platforms.

Instructions for placing maximum height signs.

Instructions for placing horizontal safety nets.

Instructions for placing safety nets with perimeter rope supported by a gallow type support.

Instructions for placing vertical safety nets.

Instructions for placing slope stabilization netting systems.

Instructions for placing joint planks fixed to the slab.

Instructions for placing excavated land material as a protective barrier.

Instructions for placing safety fences.

Instructions for placing safety canopies.

Instructions for placing safety devices in vehicles and machinery mobile parts.

Instructions for executing provisional masonry closures.

Instructions for checking periodically the existence and the maintenance status of installed collective protections.

Instructions for checking periodically the existence and the maintenance status of safety devices of tools and equipments.

Instructions for checking periodically the existence and the maintenance status of safety devices of vehicles and machinery.

Instructions for checking periodically the existence and the maintenance status of safety devices of hoists and elevators.

Instructions for checking periodically the existence and the maintenance status of safety devices of mobile work platforms.

Instructions for checking periodically the existence and the maintenance status of safety devices of cranes.

Instructions for using provisional accesses to structures.

Instructions for using provisional accesses to roofs.

Instructions for using provisional accesses to formworks.

Instructions for working in case of extreme meteorological conditions

Instructions for working under extreme cold or hot weather conditions.

Instructions for work stoppage in case of foggy conditions.

Instructions for work stoppage under heavy rains.

Instructions for work stoppage under strong winds.

Instructions for work stoppage under thunderstorms.

Instructions for delimiting workplace

Instructions for delimiting workplace in case of scaffolds assembly and use.

Instructions for delimiting workplace in case of concrete towers assembly and use.

Instructions for delimiting workplace in case of falseworks assembly and use.

Instructions for delimiting workplace in case of formwork assembly and use.

Instructions for delimiting workplace in case of fixed and mobile work platforms assembly and use.

Instructions for delimiting workplace in case of hoists and elevators assembly and use.

Instructions for delimiting workplace in case of machinery use.

Instructions for delimiting workplace in case of welding activities.

Instructions for delimiting workplace in case of asphalt membranes placing activities.

Instructions for delimiting material storage areas.

Instructions for delimiting chemical, flammable or combustible products storage areas.

Instructions for delimiting waste storage areas.

Instructions for delimiting tools and equipment storage areas.

Instructions for delimiting vehicles and machinery storage areas.

Instructions for delimiting maintenance and cleaning areas in case of tools and equipment.

Instructions for delimiting maintenance and cleaning areas in case of vehicles and machinery.

Instructions for delimiting areas affected by underground electrical lines.

Instructions for delimiting areas affected by overhead electrical lines.

Instructions for delimiting areas affected by electrical wires or hoses.

Instructions for delimiting areas affected by slippery spillages.

Instructions for delimiting areas affected by collapse or crumble risks.

Instructions for delimiting areas affected by intersections of the construction site with external road traffic.

Instructions for delimiting pedestrian, vehicles or machinery passageways.

Instructions for delimiting top and lower parts of dangerous talus slopes.

Instructions for delimiting ditches.

Instructions for signalling workplace

Instructions for signalling workplace in case of machinery use.

Instructions for signalling workplace in case of demolition activities.

Instructions for signalling workplace in case of welding activities.

Instructions for signalling workplace in case of asphalt membranes placing activities.

Instructions for signalling workplace in case of breakage or cracks in utilities susceptible to emit noxious fumes and vapours.

Instructions for signalling material storage areas.

Instructions for signalling chemical, flammable or combustible products storage areas.

Instructions for signalling waste storage areas.

Instructions for signalling tools and equipment storage areas.

Instructions for signalling vehicles and machinery storage areas.

Instructions for signalling maintenance and cleaning areas in case of tools and equipment.

Instructions for signalling maintenance and cleaning areas in case of vehicles.

Instructions for signalling areas affected by underground electric lines.

Instructions for signalling areas affected by overhead electric lines.

Instructions for signalling areas affected by electric wires or hoses.

Instructions for signalling areas affected by collapse or crumble risks.

Instructions for signalling areas affected by the intersection between construction site and traffic.

Instructions for signalling areas affected by pedestrian crossing, vehicles and machinery.

Instructions for signalling areas affected by top and lower parts of dangerous talus slopes.

Instructions for signalling ditches.

Instructions for signalling nail elements or cutting objects.

Instructions for signalling areas affected by elements in reparation.

Instructions for cleaning and tidying up

Instructions for cleaning and tidying up workplaces.

Instructions for cleaning and tidying up material storage areas.

Instructions for cleaning and tidying up chemical, flammable or combustible products storage areas.

Instructions for cleaning and tidying up waste storage areas.

Instructions for cleaning and tidying up vehicles and machinery storage areas.

Instructions for cleaning and tidying up pedestrian crossing, vehicles and machinery areas.

Instructions for regulating circulation flow

Instructions for site workers circulation in predefined passageways.

Instructions for site workers circulation in irregular surface areas.

Instructions for site workers circulation in areas with reinforcing bars.

Instructions for vehicles and machinery circulation.

Instructions for circulation restriction in case of breakage or cracks in utilities susceptible to emit noxious fumes and vapours.

Instructions for circulation restriction in case of landslides.

Instructions for stabilizing and paving vehicles and machinery passageways.

Instructions for wetting vehicles and machinery passageways.

Instructions for placing tools and equipment in without causing interference.

Instructions for placing vehicles and machinery in without causing interference.

Instructions for placing materials and waste in without causing interference.

Instructions for placing hoists and elevators in without causing interference.

Instructions for working with attention to the workplace surrounding area conditions

Instructions for working in natural or mechanical well ventilated areas.

Instructions for identifying excavations and working near its surrounding area.

Instructions for identifying overhead electric lines and working near its surrounding area.

Instructions for identifying underground electric lines and working near its surrounding area.

Instructions for identifying beams and working near its surrounding area.

Instructions for identifying breakage or cracks in utilities susceptible to emit noxious fumes and vapours and working near its surrounding area.

Instructions for checking land status on the first working day after long stoppages or heavy rains.

Instructions for rain channelling in talus slopes.

Instructions for regulating staff

Instructions for incorporating surveillance personnel in case of works in ditches more than 1.30 m deeper.

Instructions for incorporating signalling personnel in case of works with cranes.

Instructions for incorporating signalling personnel in case of works with machinery manoeuvres.

Instructions for incorporating utility company personnel in case of breakage or cracks in utilities susceptible to emit noxious fumes and vapours.

Instructions for incorporating utility company personnel in case of works with overhead electric lines interception.

Instructions for incorporating utility company personnel in case of works with underground electric lines interception.

Instructions for incorporating fire-fighting trained personnel in case of welding activities.

Instructions for reporting workers in case of overhead electrical lines interception.

Instructions for reporting workers in case of underground electrical lines interception.

Instructions for reporting workers in case of breakage or cracks in utilities susceptible to emit noxious fumes and vapours interception.

Instructions for ingesting drinks and food.

Instructions for ingesting hot drinks and food in case of extremely cold or hot weather conditions.

Instructions for ingesting alcoholic or narcotic drinks or food.

Instructions for adopting personal active immunization.

Instructions for adopting personal audiometric control.

Instructions for adopting action measures in case of prinks and injuries.

Instructions for personal ergonomics

Instructions for adopting correct positions in case of tools and equipments handling.

Instructions for adopting correct positions in case of loads handling.

Instructions for adopting correct pace of works.

Instructions for adopting organizational measures of job rotation in case of extreme cold or hot weather conditions.

Instructions for adopting organizational measures of job rotation in case of tools and equipment handling.

Instructions for adopting organizational measures of job rotation in case of loads handling.

Instructions for adopting organizational measures of job rotation in case of noisily or vibration environments.

Instructions for adopting organizational measures of job rotation in case of exposure to dust, fibres, fumes, steams or gases.

Instructions for handling and transporting loads manually.

Instructions for handling and transporting suspended loads.

Instructions for saving water

Instructions for saving water by detecting on-site water leaks.

Instructions for saving water by reusing on-site ground water.

Instructions for saving water by reusing rainwater.

Instructions for saving water by reusing sewage water.

Instructions for saving water in case of soaking bricks.

Instructions for saving water in case of curing concrete slabs.

Instructions for saving water in case of wetting vehicles and machinery passageways.

Instructions for saving water in case of wetting dusty materials.

Instructions for purchasing, transporting, storing and handling resources

Instructions for transporting materials.

Instructions for transporting dusty materials.

Instructions for purchasing material by achieving zero surplus.

Instructions for purchasing material achieving minimum stocks on-site.

Instructions for purchasing material to minimize its quantity and/or dangerousness.

Instructions for identifying and adequating earth and material storage areas.

Instructions for stocking up materials, waste, tools and equipment in suitable places and in an orderly manner.

Instructions for storing and handling materials.

Instructions for storing and handling dusty materials.

Instructions for storing and handling chemical, flammable or combustible products.

Instructions for storing and handling food products.

Instructions for handling tools and equipments.

Instructions for handling welding tools and equipments in both dry and wet environments.

Instructions for handling tools and combustion engine equipments.

Instructions for provisioning tool belts, boxes or cases.

Instructions for accessing to mobile machinery.

Instructions for cautious driving according to traffic regulation.

Instructions for using cutting machinery with water or aspiration systems.

Instructions for maintaining resources

Instructions for maintaining auxiliary elements.

Instructions for maintaining tools and equipments.

Instructions for maintaining vehicles and machinery.

Instructions for revising quality seals and technical inspections in auxiliary elements.

Instructions for revising quality seals and technical inspections in tools and equipment.

Instructions for revising quality seals and technical inspections in vehicles and machinery.

Instructions for periodical cleaning of tools and equipment.

Instructions for periodical cleaning of mortar and concrete devices.

Instructions for periodical cleaning of vehicles and machinery.

Instructions for periodical cleaning of concrete agitator trucks.

Instructions for managing waste

Instructions for defining waste management scenario.

Instructions for waste minimization.

Instructions for managing earth.

Instructions for managing inert waste.

Instructions for managing non-hazardous waste.

Instructions for managing hazardous waste.

Instructions for managing black sewages.

Instructions for managing residual waters.

Instructions for thixotropic fluids.

Instructions for managing accidental dumping on soil.

Instructions for managing accidental dumping on river flows or sewage system.

Instructions for managing fumes emissions in case of bad combustion in tools, equipments, vehicles or machinery.

Instructions for managing accidental dust emissions in case of dusty materials use or vertical transportation of rubble.

Instructions for managing accidental dust emissions in case of tools, equipments, vehicles or machinery.

Instructions for waste management transferring to the supplier.

Instructions for waste management transferring to the subcontractor.

Instructions for transporting on-site vertical rubble.

Instructions for treating concrete surplus.

Instructions for using crushers.

Instructions for regulating noise

Instructions for measuring on-site noise and mechanical vibrations.

Instructions for establishing and executing an organisational and technical program to reduce on-site noise and mechanical vibrations exposure.

Instructions for regulating actions on biodiversity

Instructions for protecting plants.

Instructions for protecting biodiversity.

Instructions for protecting topsoil.

Instructions for protecting erosion-sensitive taluses.

Instructions for protecting water table.

Instructions for protecting water systems.

Instructions for avoiding soil compaction.

Instructions for restoring provisional on-site facilities occupation.

Instructions for dealing with community

Instructions for notifying affected people of temporary traffic cuts.

Instructions for notifying affected people of noise emission levels and its schedule.

Instructions for managing complaints.

Instructions for regulating electrical facilities

Instructions for providing workplaces with on-site artificial lighting installations and periodically checking them.

Instructions for providing storage areas with on-site artificial lighting installations and periodically checking them.

Instructions for providing hoist and elevators stops with on-site artificial lighting installations and periodically checking them.

Instructions for providing areas with stairs under construction with on-site artificial lighting installations and periodically checking them.

Instructions for providing vehicles and machinery with on-site artificial lighting installations and periodically checking them.

Instructions for providing workplaces with on-site electrical power installations and periodically checking them.

Instructions for providing storage areas with on-site electrical power installations and periodically checking them.

Instructions for executing wire installation in both wet and dry environments.

Instructions for electrical panel characteristics in both wet and dry environments.

Instructions for acting in case of emergency situations

Instructions for prohibiting smoking at workplaces.

Instructions for prohibiting smoking at storage areas.

Instructions for prohibiting smoking in case of breakage or cracks in utilities susceptible to emit noxious fumes and vapours.

Instructions for prohibiting spark generation activities in case of chemical products, flammable or combustible storage areas.

Instructions for prohibiting spark generation activities in case of breakage or cracks in utilities susceptible to emit noxious fumes and vapours.

Instructions for acting in case of fire or explosion at workplaces.

Instructions for acting in case of fire or explosion in storage areas.

Instructions for acting in case of fire or explosion in chemical, flammable or combustible products storage areas.

Instructions for acting in case of fire or explosion in ruptures or cracks in gas or combustible services.

Instructions for acting in case of fire or explosion in electric facilities.

Instructions for acting in case of fire or explosion in vehicles and machinery.

Instructions for defining a safety protocol in case of breakage or cracks in utilities susceptible to emit noxious fumes and vapours.

Instructions for defining a safety protocol in case of welding activities.

Instructions for executing construction activities

Instructions for executing ditches.

Instructions for executing metallic structures.

Instructions for executing staircases.

Instructions for executing works with nails.

Instructions for executing demolition activities.

Instructions for executing reinforcement activities.

Instructions for executing welding activities in both wet and dry environments.

Instructions for executing concreting activities.

Instructions for executing insulation placing activities.

Instructions for executing asphalt placing activities.

Instructions for executing painting activities.

Instructions for executing cutting activities.

Instructions for assembling and using auxiliary elements

Instructions for assembling and using scaffolds.

Instructions for assembling and using hoists and elevators.

Instructions for assembling and using concrete head frames.

Instructions for assembling and using falseworks.

Instructions for assembling and using formworks.

Instructions for assembling and using manual ladders.

Instructions for assembling and using provisional catwalks.

Instructions for assembling and using fixed and mobile work platforms.

Instructions for assembling and using cranes.

ENVIRONMENTAL IMPACTS		CP	WI
ATMOSPHERIC EMISSIONS		26	22
AE-1	Generation of greenhouse gas emissions due to construction machinery and vehicle movements.	20	13
AE-2	Emission of VOCs and CFCs.	6	9
WATER EMISSIONS		83	35
WE-1	Dumping of water resulting from the execution of foundations and retaining walls.	8	12
WE-2	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	74	17
WE-3	Dumping of sanitary water resulting from on-site sanitary conveniences.	1	6
WASTE GENERATION		284	97
WG-1	Generation of excavated waste material during earthworks.	16	15
WG-2	Generation of municipal waste by on-site construction workers.	4	22
WG-3	Generation of inert waste.	87	28
WG-4	Generation of ordinary or non-special waste (wood, plastic, metal, paper, cardboard or glass).	145	25
WG-5	Generation of special (potentially dangerous) waste.	32	7
SOIL ALTERATION		265	144
SA-1	Land occupancy by the building, provisional on-site facilities and storage areas.	49	48
SA-2	Use of concrete release agent at the construction site.	2	19
SA-3	Use of cleaning agents or surface-treatment liquids at the construction site.	44	20
SA-4	Dumping derived from the use and maintenance of construction machinery.	86	20
SA-5	Dumping of water resulting from the execution of foundations and retaining walls.	8	13
SA-6	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	75	17

ENVIRONMENTAL IMPACTS		**CP**	**WI**
SA-7	Dumping of sanitary water resulting from on-site sanitary conveniences.	1	7
RESOURCE CONSUMPTION		539	76
RC-1	Water consumption during the construction process.	99	13
RC-2	Electricity consumption during the construction process.	200	8
RC-3	Fuel consumption during the construction process.	32	20
RC-4	Raw materials consumption during the construction process.	208	35
LOCAL ISSUES		15	9
L-4	Operations that cause dirtiness at the construction site entrances.	1	7
L-6	Landscape alteration by the presence of singular elements (cranes).	14	2
TRANSPORT ISSUES		5	20
T-1	Increase in external road traffic due to construction site transport.	4	6
T-2	Interference in external road traffic due to the construction site.	1	14
EFFECTS ON BIODIVERSITY		82	47
B-1	Operations with vegetation removal (site preparation).	4	19
B-2	Operations with loss of edaphic soil (site preparation).	14	3
B-3	Operations with high potential soil erosion (unprotected soils as a consequence of earthworks).	9	3
B-4	Opening construction site entrances with soil compaction.	6	18
B-5	Interception of river beds, integration of river beds in the development, water channelling and stream water cutoff.	49	4
TOTAL		**1,299**	**450**

Table C.1. Number of established relationships between 'Environmental Impacts', 'Construction Processes' (CP) and 'Work Instructions' (WI) within the ontology-based approach for on-site integrated environmental and health and safety management.

HEALTH AND SAFETY RISKS		CP	WI
FALLS BETWEEN DIFFERENT LEVELS		259	236
FH-1	Falls between different levels during small demolition operations, earthworks and foundation work.	16	43
FH-2	Falls between different levels during structural work.	29	42
FH-3	Falls between different levels during roof work.	70	37
FH-4	Falls between different levels during work on facades, partition walls and vertical coatings.	65	37
FH-5	Falls between different levels during floor work.	39	21
FH-6	Falls between different levels during work on door and window closures.	13	31
FH-7	Falls between different levels during work on false ceilings and ceiling coatings.	27	25
FALLS AT THE SAME LEVEL		129	168
FS-1	Falls at the same level during small demolition operations and earthworks.	4	49
FS-2	Falls at the same level during reinforcement work.	31	38
FS-3	Falls at the same level during roof work.	53	41
FS-4	Falls at the same level during work on partition walls and vertical coatings.	41	40
FALLING OBJECTS DUE TO CRUMBLE OR COLLAPSE		91	128
FOC-1	Injuries from falling objects due to crumble or collapse during earthworks.	6	30
FOC-2	Injuries from falling objects due to crumble or collapse due to the use of in-situ concrete.	33	31
FOC-3	Injuries from falling objects due to crumble or collapse during cladding work on facades.	23	26
FOC-4	Injuries from falling objects due to crumble or collapse during cladding work on partition walls.	23	21
FOC-5	Injuries from falling objects due to crumble or collapse during false ceiling work.	6	20

HEALTH AND SAFETY RISKS		CP	WI
FALLING OBJECTS DURING HANDLING		50	71
FOH-1	Injuries from falling objects during materials and waste management operations.	1	17
FOH-2	Injuries from falling objects during handling in prefabricated structure assembly.	23	18
FOH-3	Injuries from falling objects during handling in cladding work.	10	19
FOH-4	Injuries from falling objects during handling in work on door and window closures.	16	17
OBJECTS FALLING FROM ABOVE		126	233
OF-1	Injuries from objects falling from above during materials and waste management operations.	1	41
OF-2	Injuries from objects falling from above during earthworks.	5	24
OF-3	Injuries from objects falling from above during structural work.	29	42
OF-4	Injuries from objects falling from above during roof work.	14	35
OF-5	Injuries from objects falling from above during work on facades and vertical coatings.	38	37
OF-6	Injuries from objects falling from above during work on partition walls and vertical coatings.	38	28
OF-7	Injuries from objects falling from above during false ceiling work.	1	26
STEPPING ON OBJECTS		23	80
SO-1	Injuries from stepping on objects during small demolition operations.	1	24
SO-2	Injuries from stepping on objects during removal of garden elements.	1	22
SO-3	Injuries from stepping on reinforcing bars, screws or nails.	21	34
HITTING STATIONARY OBJECTS		27	112
HS-1	Injuries from hitting stationary objects in provisional on-site facilities and storage areas.	1	44
HS-2	Injuries from hitting stationary objects during small demolition operations.	1	23

HEALTH AND SAFETY RISKS		CP	WI
HS-3	Injuries from hitting stationary objects during removal of garden elements.	1	22
HS-4	Injuries from hitting stationary objects during structural work.	24	23
HITTING MOVING OBJECTS		47	158
HM-1	Injuries from hitting moving parts of machinery during materials and waste management operations.	2	38
HM-2	Injuries from hitting moving parts of machinery during earthworks.	12	30
HM-3	Injuries from hitting moving parts of machinery during foundation work.	4	31
HM-4	Injuries from hitting moving parts of machinery during structural work.	20	32
HM-5	Injuries from hitting moving parts of machinery during work on concrete foundations and floors.	9	27
CUTS OR BLOWS FROM OBJECTS AND TOOLS		126	136
CS-1	Injuries from cuts or blows from objects and tools during removal of garden elements.	1	16
CS-2	Injuries from cuts or blows from objects and tools during work on foundation and structure.	31	32
CS-3	Injuries from cuts or blows from objects and tools during finishing work on roofs.	14	23
CS-4	Injuries from cuts or blows from objects and tools during work on facades and partition walls.	16	22
CS-5	Injuries from cuts or blows from objects and tools during work on coatings or floors.	57	23
CS-6	Injuries from cuts or blows from objects and tools during work on false ceilings.	7	20
PROJECTION OF FRAGMENTS AND PARTICLES		61	48
FF-1	Injuries from projection of fragments and particles in cutting operations.	48	18
FF-2	Injuries from projection of fragments and particles in concrete operations.	8	14

HEALTH AND SAFETY RISKS		CP	WI
FF-3	Injuries from projection of fragments and particles in spray-gun painting operations.	5	16
BECOMING CAUGHT IN OR BETWEEN OBJECTS		30	146
CO-1	Injuries from becoming caught in or between objects during materials and waste management operations.	2	27
CO-2	Injuries from becoming caught in or between objects during small demolition operations.	1	16
CO-3	Injuries from becoming caught in or between objects during removal of garden elements.	1	15
CO-4	Injuries from becoming caught in or between objects during earthworks.	10	25
CO-5	Injuries from becoming caught in or between objects during work on piles, micro-piles and screen walls.	7	19
CO-6	Injuries from becoming caught in or between objects in forming and shoring operations.	8	19
CO-7	Injuries from becoming caught in or between objects in operations with scaffoldings or working platforms.	1	25
BECOMING CAUGHT IN CUMPED VEHICLES OR MACHINES		51	118
CV-1	Injuries from becoming caught in dumped vehicles or machines during materials and waste management operations.	2	25
CV-2	Injuries from becoming caught in dumped vehicles or machines during earthworks.	13	32
CV-3	Injuries from becoming caught in dumped vehicles or machines during foundation work.	7	22
CV-4	Injuries from becoming caught in dumped vehicles or machines during structural work.	20	24
CV-5	Injuries from becoming caught in dumped vehicles or machines during structural work.	9	15
OVEREXERTION, BAD POSTURE OR REPETITIVE MOTION		44	14
OX-1	Injuries from overexertion, bad posture or repetitive motion.	44	14
EXPOSURE TO EXTREME TEMPERATURES		220	15
ET-1	Injuries from exposure to extreme temperatures.	220	15

HEALTH AND SAFETY RISKS		CP	WI
THERMAL CONTACTS		18	44
TC-1	Injuries from thermal contacts due to specific welding operations.	9	29
TC-2	Injuries from thermal contacts due to joining waterproof membranes.	9	15
ELECTRIC CONTACTS		226	76
EC-1	Injuries from electrical contacts with active elements.	207	23
EC-2	Injuries from electrical contacts due to breakage of underground electric power cables.	16	16
EC-3	Injuries from electrical contacts due to contact with balling pumps.	2	14
EC-4	Injuries from electrical contacts due to contacts with overhead electric power lines.	1	23
EXPOSURE HARMFUL OR TOXIC SUBSTANCES		60	117
EH-1	Injuries from exposure to harmful or toxic substances during materials and waste management operations.	4	24
EH-2	Injuries from exposure to harmful or toxic substances during specific welding operations.	18	21
EH-3	Injuries from exposure to harmful or toxic substances due to the use of concrete release agents at the construction site.	4	19
EH-4	Injuries from exposure to harmful or toxic substances due to joining waterproof membranes.	20	20
EH-5	Injuries from exposure to harmful or toxic substances due to the use of synthetic paints and varnishes.	12	19
EH-6	Injuries from exposure to harmful or toxic substances in surface-polishing operations.	2	14
CONTACT WITH CAUSTIC OR CORROSIVE SUBSTANCES		144	56
CC-1	Injuries from contact with caustic or corrosive substances during work on foundations and in-situ concrete structures.	32	19
CC-2	Injuries from contact with caustic or corrosive substances during work on brick closures and coatings.	100	19
CC-3	Injuries from contact with caustic or corrosive substances during work on concrete foundations and floors.	12	18

HEALTH AND SAFETY RISKS		**CP**	**WI**
EXPOSURE TO RADIATION		9	15
ER-1	Injuries from exposure to radiation due to specific welds.	9	15
FIRES AND EXPLOSIONS		9	30
AC-4	Injuries from fires due to specific welds.	9	30
BEING HIT OR RUN OVER BY VEHICLES		56	164
HV-1	Injuries from being hit or run over by vehicles during material transport operations.	12	38
HV-2	Injuries from being hit or run over by vehicles during earthworks.	13	42
HV-3	Injuries from being hit or run over by vehicles during foundation work.	11	42
HV-4	Injuries from being hit or run over by vehicles in prefabricated structure assembly.	20	42
TRAFFIC ACCIDENTS		11	58
TA-1	Injuries from external or internal traffic accidents.	11	58
TOTAL		**1,806**	**2,165**

Table C.2. Number of established relationships between 'Health and Safety Risks', 'Construction Processes' (CP) and 'Work Instructions' (WI) within the ontology-based approach for on-site integrated environmental and health and safety management.

ENVIRONMENTAL IMPACTS / HEALTH AND SAFETY RISKS		**CP**	**WI**
L-1	Dust generation in activities with construction machinery and transport.	1	17
L-2	Dust generation in earthworks activities and stockpiles.	16	21
L-3	Dust generation in activities with cutting operations.	81	16
L-5	Generation of noise and vibrations due to site activities.	97	26
AC-1	Fires at areas for storing flammable and combustible substances.	2	32
AC-2	Breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes).	7	30
AC-3	Breakage of receptacles with harmful substances. Storage tanks for dangerous products.	5	34
TOTAL		**209**	**176**

Table C.3. Number of established relationships between common 'Environmental Impacts' and 'Health and Safety Risks', 'Construction Processes' (CP) and 'Work Instructions' (WI) within the ontology-based approach for on-site integrated environmental and health and safety management.

Appendix

D. Assessment results for construction projects

D.1 Case study 1

CONSTRUCTION SAFETY RISK		IN-SITU CONCRETE STRUCTURE		PRECAST CONCRETE STRUCTURE	
		P	**EX**	**P**	**EX**
FS-2	Falls at the same level during reinforcement work.	10,725.6	9	Prefabricated structure.	1
		647.2	9	647.2	9
FOC-2	Injuries from falling objects due to crumble or collapse due to the use of in-situ concrete.	319.74	9	93.74	1
FOH-2	Injuries from falling objects during handling in prefabricated structure assembly.	No prefabricated structures.	0	2,241.18	9
OF-3	Injuries from objects falling from above during structural work.	0.1008	9	Prefabricated structure.	1
SO-3	Injuries from stepping on reinforcing bars, screws or nails.	Unknown formwork: 226.000	9	0.000	0
		10,725.6	9	Prefabricated structure.	1
HS-4	Injuries from hitting stationary objects during structural work.	0.1008	9	Prefabricated structure.	1

CONSTRUCTION SAFETY RISK		IN-SITU CONCRETE STRUCTURE		PRECAST CONCRETE STRUCTURE	
		P	**EX**	**P**	**EX**
HM-4	Injuries from hitting moving parts of machinery during structural work.	0.1008	9	Prefabricated structure.	1
CS-2	Injuries from cuts or blows from objects and tools during work on foundation and structure.	319.74	9	Prefabricated structure.	1
CO-6	Injuries from becoming caught in or between objects in forming and shoring operations.	226.000	9	0.000	0
EH-3	Injuries from exposure to harmful or toxic substances due to the use of concrete release agents at the construction site.	The structure of the building (or most of its facades) is made of in-situ concrete.	9	Neither the structure of the building nor its facades are made on in-situ concrete.	1
CC-1	Injuries from contact with caustic or corrosive substances during work on foundations and in-situ concrete structures.	319.74	9	Prefabricated structure.	1

CONSTRUCTION SAFETY RISK		IN-SITU CONCRETE STRUCTURE		PRECAST CONCRETE STRUCTURE	
		P	**EX**	**P**	**EX**
HV-4	Injuries from being hit or run over by vehicles in prefabricated structure assembly.	No prefabricated structures.	0	2,241.18	9
SAFETY RISK LEVEL			**108**		**36**

Table D.1. Case study 1: assessment of the safety-related performance of designing an in-situ concrete structure or a precast structure in a multi-family dwelling.

ENVIRONMENTAL ASPECT		IN-SITU CONCRETE STRUCTURE				PRECAST CONCRETE STRUCTURE			
		P	**MG**	**EN**	**SG_E**	**P**	**MG**	**EN**	**SG_E**
WE-2	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	0.1427	1	3	3	0.0418	1	3	3
SA-2	Use of concrete release agent at the construction site.	In-situ concrete	3	5	15	No in-situ concrete	1	5	5

ENVIRONMENTAL ASPECT		IN-SITU CONCRETE STRUCTURE				PRECAST CONCRETE STRUCTURE			
		P	**MG**	**EN**	**SG_E**	**P**	**MG**	**EN**	**SG_E**
SA-6	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	0.1427	1	5	5	0.0418	1	5	5
RC-1	Water consumption during the construction process.	0.14018	5	3	15	0.02287	1	3	3
L-6	Landscape alteration by the presence of singular elements (cranes).	1	1	3	3	2	3	3	9
T-2	Interference in external road traffic due to the construction site.	0	0	1	0	5	3	1	3
ENVIRONMENTAL IMPACT LEVEL					**41**				**28**

Table D.2. Case study 1: assessment of the environmental-related performance of designing an in-situ concrete structure or a precast structure in a multi-family dwelling.

CONSTRUCTION SAFETY RISK		SLATE GABLE ROOF WITH SLOPE OF 45% AND WINDOWS FOR VENTILATION		TRAFFICABLE ROOF WITH BOUNDARY WALLS	
		P	**EX**	**P**	**EX**
FH-2	Falls between different levels during structural work.	0.3318	9	0.2313	9
FH-3	Falls between different levels during roof work.	0.1787	1	0.0000	0
FS-3	Falls at the same level during roof work.	630.000	25	541.920	9
OF-4	Injuries from objects falling from above during roof work.	0.1787	1	0.0000	0
CS-3	Injuries from cuts or blows from objects and tools during finishing work on roofs.	630.000	25	541.920	9
SAFETY RISK LEVEL			**61**		**27**

Table D.3. Case study 1: assessment of the safety-related performance of designing a slate gable roof with a slope of 45% and windows for ventilation or a trafficable roof with boundary walls in a multi-family dwelling.

CONSTRUCTION SAFETY RISK		FACING BRICK*		MASONRY WALLS WITH NATURAL STONE CLADDING*		MASONRY WALLS WITH SINGLE-LAYER MORTAR COATING*		PRECAST CONCRETE FACADES*	
		P	**EX**	**P**	**EX**	**P**	**EX**	**P**	**EX**
FH-4	Falls between different levels during work on facades, partition walls and vertical coatings.	9,383.5	9	9,383.5	9	9,383.5	9	9,383.5	9
		972.87	9	2,918,61	9	3,891,48	9	972,87	9
FOC-3	Injuries from falling objects due to crumble or collapse during cladding work on facades.	0.000	0	972.87	25	0.000	0	0.000	0
FOH-3	Injuries from falling objects during handling in cladding work.	No heavy cladding.	0	Heavy claddings	9	No heavy cladding.	0	No heavy cladding.	0
OF-5	Injuries from objects falling from above during work on facades and vertical coatings.	972.87	9	2,918.61	9	3,891.48	9	972.87	9
CS-5	Injuries from cuts or blows from objects and tools during work on coatings or floors.	100.00%	25	0.00%	0	0.00%	0	0.00%	0
		25.13%	1	40.75%	9	25.13%	1	25.13%	1

CONSTRUCTION SAFETY RISK		FACING BRICK*		MASONRY WALLS WITH NATURAL STONE CLADDING*		MASONRY WALLS WITH SINGLE-LAYER MORTAR COATING*		PRECAST CONCRETE FACADES*	
		P	**EX**	**P**	**EX**	**P**	**EX**	**P**	**EX**
FF-1	Injuries from projection of fragments and particles in cutting operations.	100.00%	25	0.00%	0	0.00%	0	0.00%	0
		1,020.42	9	1,020.42	9	1,020.42	9	1,020.42	9
		25.13%	1	40.75%	9	25.13%	1	25.13%	1
FF-3	Injuries from projection of fragments and particles in spray-gun painting operations.	0.00%	0	0.00%	0	100.00%	25	0.00%	0
CC-2	Injuries from contact with caustic or corrosive substances during work on brick closures and coatings.	81.90	9	107.73	9	68.67	1	0.00	0
L-3	Dust generation in activities with cutting operations.	100.00%	25	0.00%	0	0.00%	0	0.00%	0
		25.13%	1	40.75%	9	25.13%	1	25.13%	1
SAFETY RISK LEVEL			**133**		**116**		**75**		**49**

* In case of dry partition walls.

Table D.4. Case study 1: assessment of the safety-related performance of designing in-situ facades (facing brick, masonry walls with natural stone cladding and, masonry walls with single-layer mortar coating) or precast facades (precast concrete panels without in-situ claddings) in a multi-family dwelling.

ENVIRONMENTAL ASPECT		FACING BRICK*				MASONRY WALLS WITH NATURAL STONE CLADDING*				MASONRY WALLS WITH SINGLE-LAYER MORTAR COATING*				PRECAST CONCRETE FACADES*			
		P	**MG**	**EN**	**SG_E**	**P**	**MG**	**EN**	**SG_E**	**P**	**MG**	**EN**	**SG_E**	**P**	**MG**	**EN**	**SG_E**
AE-2	Emission of VOCs and CFCs.	0.00%	0	5	0	0.00%	0	5	0	100.00%	5	5	25	0.00%	0	5	0
SA-3	Use of cleaning agents or surface-treatment liquids at the construction site.	100.00%	5	5	25	0.00%	0	5	0	0.00%	0	5	0	0.00%	0	5	0
		25.13%	1	5	5	40.75%	3	5	15	25.13%	1	5	5	25.13%	1	5	5
L-3	Dust generation in activities with cutting operations.	100.00%	5	3	15	0.00%	0	3	0	0.00%	0	3	0	0.00%	0	3	0
		25.13%	1	3	3	40.75%	3	3	9	25.13%	1	3	3	25.13%	1	3	3
ENVIRONMENTAL IMPACT LEVEL					**48**				**24**				**33**				**8**

* In case of dry partition walls.

Table D.5. Case study 1: assessment of the environmental-related performance of designing in-situ facades (facing brick, masonry walls with natural stone cladding and masonry walls with single-layer mortar coating) or precast facades (precast concrete panels without in-situ claddings) in a multi-family dwelling.

CONSTRUCTION SAFETY RISK		BALCONIES WITH WOOD RAILINGS		BALCONIES WITH BOUNDARY WALLS	
		P	**EX**	**P**	**EX**
FH-5	Falls between different levels during floor work.	0.1950	25	0.1031	9
FH-6	Falls between different levels during work on door and window closures.	42.00	9	30.00	9
SAFETY RISK LEVEL			**34**		**18**

Table D.6. Case study 1: assessment of the safety-related performance of designing balconies with wood railings or balconies with boundary walls in a multi-family dwelling.

CONSTRUCTION SAFETY RISK		NATURAL WOOD FLOORS		ARTIFICIAL WOOD FLOORS	
		P	**EX**	**P**	**EX**
EH-6	Injuries from exposure to harmful or toxic substances in surface-polishing operations.	Floor area made from natural wood or other materials that require polishing.	9	No floor area made from natural wood or other materials that require polishing.	0
SAFETY RISK LEVEL			**9**		**0**

Table D.7. Case study 1: assessment of the safety-related performance of designing natural or artificial wood floors in a multi-family dwelling.

CONSTRUCTION SAFETY RISK		WATERPROOF LAYER JOINTS SEALED OFF BY APPLYING HEAT		WATERPROOF LAYER JOINTS SEALED OFF BY MECHANICAL MEANS	
		P	**EX**	**P**	**EX**
TC-2	Injuries from thermal contacts due to joining waterproof membranes.	Waterproof layer joints are sealed off by applying heat.	9	Waterproof layer joints are sealed off by mechanical or adhesive means.	0
EH-4	Injuries from exposure to harmful or toxic substances due to joining waterproof membranes.	Waterproof layer joints are sealed off by applying heat.	9	Waterproof layer joints are sealed off by mechanical or adhesive means.	0
SAFETY RISK LEVEL			**18**		**0**

Table D.8. Case study 1: assessment of the safety-related performance of designing waterproof layer joints sealed off by applying heat or by mechanical means in a multi-family dwelling.

CONSTRUCTION SAFETY RISK		**WINDOW CLOSURES:** **2 m wide per 2 m of height.**		**WINDOW CLOSURES:** **0.80 m wide per 0.80 m of height.**	
		P	**EX**	**P**	**EX**
FOH-4	Injuries from falling objects during handling in work on door and window closures.	Windows are more than 1 m wide per 1 m of height.	25	Windows are less than 1 m wide per 1 m of height.	9
SAFETY RISK LEVEL			**25**		**9**

Table D.9. Case study 1: assessment of the safety-related performance of designing the size of the windows in a multi-family dwelling.

ENVIRONMENTAL ASPECT		**RECYCLED CONTENT IN RAW MATERIALS NOT PLANNED**				**RECYCLED CONTENT IN RAW MATERIALS UP TO 50%**			
		P	**MG**	**EN**	**SG_E**	**P**	**MG**	**EN**	**SG_E**
RC-4	Raw materials consumption during the construction process.	609.10	1	5	5	609.10	1	1	1
ENVIRONMENTAL IMPACT LEVEL					**5**				**1**

Table D.10. Case study 1: assessment of the environmental-related performance of designing with recycled materials in a multi-family dwelling.

ENVIRONMENTAL ASPECT		WASTE MANAGEMENT NOT PLANNED.				WASTE MANAGEMENT PLANNED, STRESSING IN-SITU REUSE.			
		P	**MG**	**EN**	**SG_E**	**P**	**MG**	**EN**	**SG_E**
WG-1	Generation of excavated waste material during earthworks.	0.6211	3	5	15	0.6211	3	1	3
WG-2	Generation of municipal waste by on-site construction workers.	30	3	5	15	30	3	1	3
WG-3	Generation of inert waste.	2,241.18	3	5	15	2,241.18	3	1	3
WG-4	Generation of ordinary or non-special waste (wood, plastic, metal, paper, cardboard or glass).	2,241.18	3	5	15	2,241.18	3	1	3
WG-5	Generation of special (potentially dangerous) waste.	2,241.18	3	5	15	2,241.18	3	1	3
ENVIRONMENTAL IMPACT LEVEL					**75**				**15**

Table D.11. Case study 1: assessment of the environmental-related performance of a construction project depending on the adopted strategy on waste management and reused elements in a multi-family dwelling.

CONSTRUCTION SAFETY RISK		P	EX
FH-1	Falls between different levels during small demolition operations, earthworks and foundation work.	0.3634	1
FH-7	Falls between different levels during work on false ceilings and ceiling coatings.	1,720.3	9
FS-1	Falls at the same level during small demolition operations and earthworks.	647.2	9
FOC-1	Injuries from falling objects due to crumble or collapse during earthworks.	1,392.06	9
FOC-4	Injuries from falling objects due to crumble or collapse during cladding work on partition walls.	971.96	9
FOC-5	Injuries from falling objects due to crumble or collapse during false ceiling work.	194.271	9
OF-2	Injuries from objects falling from above during earthworks.	2.1509	9
OF-7	Injuries from objects falling from above during false ceiling work.	194.271	9
SO-1	Injuries from stepping on objects during small demolition operations.	No elements to be demolished.	0
SO-2	Injuries from stepping on objects during removal of garden elements.	No garden elements to be removed.	0
HS-1	Injuries from hitting stationary objects in provisional on-site facilities and storage areas.	647.2	9
HS-2	Injuries from hitting stationary objects	No elements to be	0

CONSTRUCTION SAFETY RISK		P	EX
	during small demolition operations.	demolished.	
HS-3	Injuries from hitting stationary objects during removal of garden elements.	No garden elements to be removed.	0
HM-2	Injuries from hitting moving parts of machinery during earthworks.	2.1509	9
HM-3	Injuries from hitting moving parts of machinery during foundation work.	0.1448	1
HM-5	Injuries from hitting moving parts of machinery during work on concrete foundations and floors.	0.0553	9
CS-1	Injuries from cuts or blows from objects and tools during removal of garden elements.	No garden elements to be removed.	0
CS-4	Injuries from cuts or blows from objects and tools during work on facades and partition walls.	1,993.29	9
CS-6	Injuries from cuts or blows from objects and tools during work on false ceilings.	194.271	9
FF-2	Injuries from projection of fragments and particles in concrete operations.	123.9390	9
CO-2	Injuries from becoming caught in or between objects during small demolition operations.	No elements to be demolished.	0
CO-3	Injuries from becoming caught in or between objects during removal of garden elements.	No garden elements to be removed.	0
CO-4	Injuries from becoming caught in or between objects during earthworks.	1,392.06	9

CONSTRUCTION SAFETY RISK		P	EX
CO-5	Injuries from becoming caught in or between objects during work on piles, micro-piles and screen walls.	No piles, micro-piles or screen walls.	0
CO-7	Injuries from becoming caught in or between objects in operations with scaffoldings or working platforms.	2,241.18	9
CV-2	Injuries from becoming caught in dumped vehicles or machines during earthworks.	2.1509	9
CV-3	Injuries from becoming caught in dumped vehicles or machines during foundation work.	0.1448	1
CV-5	Injuries from becoming caught in dumped vehicles or machines during pavement work.	0.0553	9
OX-1	Injuries form overexertion, bad posture or repetitive motion.	All cases.	9
ET-1	Injuries from exposure to extreme temperatures.	The construction site is not located in an extremely hot or cold climate area.	0
TC-1	Injuries from thermal contacts due to specific welding operations.	The structure of the building is not metallic.	0
EC-1	Injuries from electrical contacts with active elements.	All cases.	9
EC-2	Injuries from electrical contacts due to breakage of underground electric power cables.	No underground electric power cables.	0

CONSTRUCTION SAFETY RISK		P	EX
EC-3	Injuries from electrical contacts due to contact with balling pumps.	The excavation level does not exceed the ground-water level.	0
EC-4	Injuries from electrical contacts due to contacts with overhead electric power lines.	No overhead power cables.	0
EH-1	Injuries from exposure to harmful or toxic substances during materials and waste management operations.	All cases.	9
EH-2	Injuries from exposure to harmful or toxic substances during specific welding operations.	The structure of the building is not metallic.	0
EH-5	Injuries from exposure to harmful or toxic substances due to the use of synthetic paints and varnishes.	0.000%	0
CC-3	Injuries from contact with caustic or corrosive substances during work on concrete foundations and floors.	123.9390	9
ER-1	Injuries from exposure to radiation due to specific welds.	The structure of the building is not metallic.	0
AC-1	Injuries from fires in areas for storing flammable and combustible substances.	2,241.18	9
AC-2	Injuries from breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes).	0.2888	9
AC-3	Injuries from breakage of receptacles containing harmful substances, such as storage tanks for dangerous products.	2,241.18	9

CONSTRUCTION SAFETY RISK		P	EX
AC-4	Injuries from fires due to specific welds.	The structure of the building is not metallic.	0
HV-2	Injuries from being hit or run over by vehicles during earthworks.	2.1509	9
HV-3	Injuries from being hit or run over by vehicles during foundation work.	0.1448	1
L-1	Dust generation in activities involving construction machinery or transport.	0.6211	9
L-2	Dust generation in earthworks and stockpiles.	0.6211	9
L-5	Generation of noise and vibrations due to site activities.	Normal activity.	9
SAFETY RISK LEVEL			**256**

Table D.12. Case study 1: assessment of construction safety risks not dependant on the abovementioned design alternatives in a multi-family dwelling.

ENVIRONMENTAL ASPECT		P	MG	EN	SG_E
AE-1	Generation of greenhouse gas emissions due to construction machinery and vehicle movements.	0.9211	3	5	15
WE-1	Dumping of water resulting from the execution of foundations and retaining walls.	0	0	0	0
WE-3	Dumping of sanitary water resulting from on-site sanitary conveniences.	30	3	1	3
SA-1	Land occupancy by the building, provisional on-site facilities and storage areas.	0.2888	1	1	1
SA-4	Dumping derived from the use and maintenance of construction machinery.	0.7556	3	5	15
SA-5	Dumping of water resulting from the execution of foundations and retaining walls.	0	0	5	0
SA-7	Dumping of sanitary water resulting from on-site sanitary conveniences.	30	3	5	15
RC-2	Electricity consumption during the construction process.	2,241.18	3	1	3
RC-3	Fuel consumption during the construction process.	0.9211	3	5	15
L-4	Operations that cause dirtiness at the construction site entrances.	2,241.18	3	1	3
T-1	Increase in external road traffic due to construction site transport.	2,241.18	3	1	3
B-1	Operations with vegetation removal (site preparation).	0.2888	3	1	3

ENVIRONMENTAL ASPECT		P	MG	EN	SG_E
B-2	Operations with loss of edaphic soil (site preparation).	0.2888	3	1	3
B-3	Operations with high potential soil erosion (unprotected soils as a consequence of earthworks).	0.2888	3	1	3
B-4	Opening construction site entrances with soil compaction.	35.97	1	1	1
B-5	Interception of river beds, integration of river beds in the development, water channelling and stream water cutoff.	0	0	3	0
ENVIRONMENTAL IMPACT LEVEL					**83**

Table D.13. Case study 1: assessment of environmental impacts not dependant on the abovementioned design alternatives in a multi-family dwelling.

ENVIRONMENTAL ASPECT / HEALTH AND SAFETY RISK		P	MG	EN	SG_E SG_S
L-1	Dust generation in activities with construction machinery and transport.	0.6211	3	3	9
L-2	Dust generation in earthworks activities and stockpiles.	0.6211	3	3	9
L-5	Generation of noise and vibrations due to site activities.	Normal activity during daytime (8:00-20:00) and no use of special machinery.	1	3	3
AC-1	Fires at areas for storing flammable and combustible substances.	2,241.18	3	5	15
AC-2	Breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes).	0.2888	3	1	3
AC-3	Breakage of receptacles with harmful substances. Storage tanks for dangerous products.	2,241.18	3	3	9
ENVIRONMENTAL IMPACT LEVEL / SAFETY RISK LEVEL					**48**

Table D.14. Case study 1: assessment of common environmental impacts and health and safety risks not dependant on the abovementioned design alternatives in a multi-family dwelling.

D.2 Case study 2

CONSTRUCTION SAFETY RISK		P	EX
FH-1	Falls between different levels during small demolition operations, earthworks and foundation work.	1.3529	9
FH-2	Falls between different levels during structural work.	0.3852	9
FH-3	Falls between different levels during roof work.	0.3534	9
FH-4	Falls between different levels during work on facades, partition walls and vertical coatings.	2,354.03	25
		421.36	9
FH-5	Falls between different levels during floor work.	0.0684	9
FH-6	Falls between different levels during work on door and window closures.	15	9
FH-7	Falls between different levels during work on false ceilings and ceiling coatings.	326.84	9
FS-1	Falls at the same level during small demolition operations and earthworks.	170.63	9
FS-2	Falls at the same level during reinforcement work.	1,890.6	9
		170.63	9
FS-3	Falls at the same level during roof work.	152.14	25

CONSTRUCTION SAFETY RISK		P	EX
FS-4	Falls at the same level during work on partition walls and vertical coatings.	2,354.03	25
FOC-1	Injuries from falling objects due to crumble or collapse during earthworks.	613.83	9
FOC-2	Injuries from falling objects due to crumble or collapse due to the use of in-situ concrete.	431.08	25
FOC-3	Injuries from falling objects due to crumble or collapse during cladding work on facades.	171.56	9
FOC-4	Injuries from falling objects due to crumble or collapse during cladding work on partition walls.	15.24	1
FOC-5	Injuries from falling objects due to crumble or collapse during false ceiling work.	111.46	9
FOH-1	Injuries from falling objects during materials and waste management operations.	1,331,105	25
FOH-2	Injuries from falling objects during handling in prefabricated structure assembly.	In-situ concrete structure.	0
FOH-3	Injuries from falling objects during handling in cladding work.	Heavy claddings.	9
FOH-4	Injuries from falling objects during handling in work on door and window closures.	Windows are more than 1 m wide per 1 m of height.	25

CONSTRUCTION SAFETY RISK		P	EX
OF-1	Injuries from objects falling from above during materials and waste management operations.	4,418.61	25
OF-2	Injuries from objects falling from above during earthworks.	3.5974	9
OF-3	Injuries from objects falling from above during structural work.	1.4310	25
OF-4	Injuries from objects falling from above during roof work.	0.3534	9
OF-5	Injuries from objects falling from above during work on facades and vertical coatings.	421.36	9
OF-6	Injuries from objects falling from above during work on partition walls and vertical coatings.	2,354.03	25
OF-7	Injuries from objects falling from above during false ceiling work.	111.46	9
SO-1	Injuries from stepping on objects during small demolition operations.	No elements to be demolished.	0
SO-2	Injuries from stepping on objects during removal of garden elements.	Bushes or short trees (less than 3.5 m tall) to be removed.	9
SO-3	Injuries from stepping on reinforcing bars, screws or nails.	371.68	25
		1,890.6	9
HS-1	Injuries from hitting stationary objects in provisional on-site facilities and storage areas.	170.63	9

CONSTRUCTION SAFETY RISK		P	EX
HS-2	Injuries from hitting stationary objects during small demolition operations.	No elements to be demolished.	0
HS-3	Injuries from hitting stationary objects during removal of garden elements.	Bushes or short trees (less than 3.5 m tall) to be removed.	9
HS-4	Injuries from hitting stationary objects during structural work.	1.4310	25
HM-1	Injuries from hitting moving parts of machinery during materials and waste management operations.	4,418.61	25
HM-2	Injuries from hitting moving parts of machinery during earthworks.	3.5974	9
HM-3	Injuries from hitting moving parts of machinery during foundation work.	0.3481	9
HM-4	Injuries from hitting moving parts of machinery during structural work.	1.4310	25
HM-5	Injuries from hitting moving parts of machinery during work on concrete foundations and floors.	0.1482	9
CS-1	Injuries from cuts or blows from objects and tools during removal of garden elements.	Bushes or short trees (less than 3.5 m tall) to be removed.	9
CS-2	Injuries from cuts or blows from objects and tools during work on foundation and structure.	431.08	25

CONSTRUCTION SAFETY RISK		P	EX
CS-3	Injuries from cuts or blows from objects and tools during finishing work on roofs.	152.14	25
CS-4	Injuries from cuts or blows from objects and tools during work on facades and partition walls.	925.46	9
CS-5	Injuries from cuts or blows from objects and tools during work on coatings or floors.	18.57%	9
		15.41%	1
CS-6	Injuries from cuts or blows from objects and tools during work on false ceilings.	111.46	9
FF-1	Injuries from projection of fragments and particles in cutting operations.	18.57%	9
		714.78	9
		15.41%	1
FF-2	Injuries from projection of fragments and particles in concrete operations.	44.640	9
FF-3	Injuries from projection of fragments and particles in spray-gun painting operations.	0.00	0
CO-1	Injuries from becoming caught in or between objects during materials and waste management operations.	1,331,105	25
CO-2	Injuries from becoming caught in or between objects during small demolition operations.	No elements to be demolished.	0
CO-3	Injuries from becoming caught in or between objects during removal of garden elements.	Bushes or short trees (less than 3.5 m tall) to be removed.	9

CONSTRUCTION SAFETY RISK		P	EX
CO-4	Injuries from becoming caught in or between objects during earthworks.	613.83	9
CO-5	Injuries from becoming caught in or between objects during work on piles, micro-piles and screen walls.	No piles, micro-piles or screen walls.	0
CO-6	Injuries from becoming caught in or between objects in forming and shoring operations.	431.076	25
CO-7	Injuries from becoming caught in or between objects in operations with scaffoldings or working platforms.	301.65	9
CV-1	Injuries from becoming caught in dumped vehicles or machines during materials and waste management operations.	4,418.61	25
CV-2	Injuries from becoming caught in dumped vehicles or machines during earthworks.	3.5974	9
CV-3	Injuries from becoming caught in dumped vehicles or machines during foundation work.	0.3482	9
CV-4	Injuries from becoming caught in dumped vehicles or machines during structural work.	Fixed crane	1
CV-5	Injuries from becoming caught in dumped vehicles or machines during pavement work.	0.1481	9
OX-1	Injuries form overexertion, bad posture or repetitive motion.	All cases	9

CONSTRUCTION SAFETY RISK		P	EX
ET-1	Injuries from exposure to extreme temperatures.	The construction site is not located in an extremely hot or cold climate area.	0
TC-1	Injuries from thermal contacts due to specific welding operations.	The structure of the building is not metallic.	0
TC-2	Injuries from thermal contacts due to joining waterproof membranes.	Waterproof layer joints are sealed off by applying heat.	9
EC-1	Injuries from electrical contacts with active elements.	All cases.	9
EC-2	Injuries from electrical contacts due to breakage of underground electric power cables.	No underground electric power cables.	0
EC-3	Injuries from electrical contacts due to contact with balling pumps.	The excavation level does not exceed the ground-water level.	0
EC-4	Injuries from electrical contacts due to contacts with overhead electric power lines.	No overhead electric power lines.	0
EH-1	Injuries from exposure to harmful or toxic substances during materials and waste management operations.	All cases.	9
EH-2	Injuries from exposure to harmful or toxic substances during specific welding operations.	The structure of the building is not metallic.	0

CONSTRUCTION SAFETY RISK		P	EX
EH-3	Injuries from exposure to harmful or toxic substances due to the use of concrete release agents at the construction site.	The structure of the building is made of in-situ concrete.	9
EH-4	Injuries from exposure to harmful or toxic substances due to joining waterproof membranes.	Waterproof layer joints are sealed off by applying heat.	9
EH-5	Injuries from exposure to harmful or toxic substances due to the use of synthetic paints and varnishes.	0.00%	0
EH-6	Injuries from exposure to harmful or toxic substances in surface-polishing operations.	Part of the floor area is made from natural wood.	9
CC-1	Injuries from contact with caustic or corrosive substances during work on foundations and in-situ concrete structures.	431.08	9
CC-2	Injuries from contact with caustic or corrosive substances during work on brick closures and coatings.	79.87	9
CC-3	Injuries from contact with caustic or corrosive substances during work on concrete foundations and floors.	44.640	9
ER-1	Injuries from exposure to radiation due to specific welds.	The structure of the building is not metallic.	0
AC-4	Injuries from fires due to specific welds.	The structure of the building is not metallic.	0

CONSTRUCTION SAFETY RISK		P	EX
HV-1	Injuries from being hit or run over by vehicles during material transport operations.	7,801.13	9
HV-2	Injuries from being hit or run over by vehicles during earthworks.	3.5974	9
HV-3	Injuries from being hit or run over by vehicles during foundation work.	0.3481	9
HV-4	Injuries from being hit or run over by vehicles in prefabricated structure assembly.	In-situ concrete structure.	0
TA-1	Injuries from external or internal traffic accidents.	3.5974	9
		7,801.13	9
SAFETY RISK LEVEL			**931**

Table D.15. Case study 2: assessment of the safety performance related to the execution of a single-family house during the planning stage in a single-family house.

ENVIRONMENTAL ASPECT		MG		EN		SG_E
AE-1	Generation of greenhouse gas emissions due to construction machinery and vehicle movements.	2.0376	3	All cases	5	15
AE-2	Emission of VOCs and CFCs.	0.00%	0	All cases	5	0
WE-1	Dumping of water resulting from the execution of foundations and retaining walls.	0.0000	0	Connection to sewage system.	3	0
WE-2	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	1.4310	5	Connection to sewage system.	3	15
WE-3	Dumping of sanitary water resulting from on-site sanitary conveniences.	6	3	Connection to sewage system.	1	3
WG-1	Generation of excavated waste material during earthworks.	0.8764	3	Delivery to an authorized manager being unaware of the final waste destination.	3	9

ENVIRONMENTAL ASPECT		MG		EN		SG_E
WG-2	Generation of municipal waste by on-site construction workers.	6	3	Non selective waste collection and delivery to an authorized manager.	5	15
WG-3	Generation of inert waste.	301.65	3	Non selective waste collection and delivery to an authorized manager.	5	15
WG-4	Generation of ordinary or non-special waste (wood, plastic, metal, paper, cardboard or glass).	301.65	3	Non selective waste collection and delivery to an authorized manager.	5	15
WG-5	Generation of special (potentially dangerous) waste.	301.65	3	Non selective waste collection and delivery to an authorized manager.	5	15
SA-1	Land occupancy by the building, provisional on-site facilities and storage areas.	0.5664	3	The affected area is placed outside the construction site perimeter.	3	9
SA-2	Use of concrete release agent at the construction site.	The structure of the building is made of in-situ concrete.	3	Urban area.	1	3
SA-3	Use of cleaning agents or surface-treatment liquids at the construction site.	18.57%	3	Urban area.	1	3
		15.41%	1			

ENVIRONMENTAL ASPECT		MG		EN		SG_E
SA-4	Dumping derived from the use and maintenance of construction machinery.	2.0557	3	Urban area.	1	3
SA-5	Dumping of water resulting from the execution of foundations and retaining walls.	0.0000	0	Urban area.	1	0
SA-6	Dumping of water resulting from the process of cleaning concrete chutes or dumping of other basic fluids.	1.6289	5	Urban area.	1	5
SA-7	Dumping of sanitary water resulting from on-site sanitary conveniences.	6	3	Urban area.	1	3
RC-1	Water consumption during the construction process.	0.3578	5	Use of water from the water network.	1	5
RC-2	Electricity consumption during the construction process.	301.65	3	Use of electricity from the electricity network.	1	3
RC-3	Fuel consumption during the construction process.	2.0376	3	All cases	5	15

ENVIRONMENTAL ASPECT		MG		EN		SG_E
RC-4	Raw materials consumption during the construction process.	4,418.61	5	Non-existence of information about recycled content raw materials.	5	25
L-4	Operations that cause dirtiness at the construction site entrances.	301.65	3	Construction site located in urban area.	5	15
L-6	Landscape alteration by the presence of singular elements (cranes).	1 crane	3	Urban area without immediate historic-artistic buildings.	1	3
T-1	Increase in external road traffic due to construction site transport.	301.65	3	Construction site located in low traffic roads.	1	3
T-2	Interference in external road traffic due to the construction site.	0 traffic cuts in non-instantaneous periods of time.	0	Construction site located in low traffic roads.	1	0
B-1	Operations with vegetation removal (site preparation).	0.5664	3	The affected area is placed outside the construction site perimeter whenever there is no vegetation.	1	3

ENVIRONMENTAL ASPECT		MG		EN		SG_E
B-2	Operations with loss of edaphic soil (site preparation).	0.5664	3	The affected area is placed outside the construction site perimeter whenever there is no edaphic soil.	1	3
B-3	Operations with high potential soil erosion (unprotected soils as a consequence of earthworks).	0.5664	3	The affected area is placed outside the construction site perimeter.	3	9
B-4	Opening construction site entrances with soil compaction.	0	0	The affected area is placed outside the construction site perimeter.	3	0
B-5	Interception of river beds, integration of river beds in the development, water channelling and stream water cutoff.	0 contact points with river beds.	0	Non-existence of natural river beds.	1	0
ENVIRONMENTAL IMPACT LEVEL						**212**

Table D.16. Case study 2: assessment of the environmental performance related to the execution of a single-family house during the planning stage in a single-family house.

ENVIRONMENTAL ASPECT / HEALTH AND SAFETY RISK		MG		EN		SG_E
L-1	Dust generation in activities with construction machinery and transport.	2.0376	3	Construction site located in urban areas.	5	15
L-2	Dust generation in earthworks activities and stockpiles.	2.0376	3	Construction site located in urban areas.	5	15
L-3	Dust generation in activities with cutting operations.	18.57%	3	Construction site located in urban areas.	5	15
		15.41%	1			
L-5	Generation of noise and vibrations due to site activities.	Normal activity during daytime hours (8:00-20:00) and no use of special machinery	1	Residential area.	3	3
AC-1	Fires at areas for storing flammable and combustible substances.	301.65	3	Distance to nearby occupied buildings lower than 100 m.	5	15
AC-2	Breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes).	0.5664	3	Urban areas with more than 100 inhabitants and the construction site is less than 500 m from a fire station.	5	15

ENVIRONMENTAL ASPECT / HEALTH AND SAFETY RISK		MG		EN		SG_E
AC-3	Breakage of receptacles with harmful substances. Storage tanks for dangerous products.	301.65	3	Construction site located in high density population area.	5	15
ENVIRONMENTAL IMPACT LEVEL / SAFETY RISK LEVEL						**93**

Table D.17. Case study 2: assessment of common environmental impacts and health and safety risks related to the execution of a single-family house during the planning stage in a single-family house.