An ontology-based approach for on-site integrated environmental and health and safety management

Un enfoque basado en ontología para la gestión integrada del medio ambiente y de la seguridad y la salud en obra

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Abstract

This paper presents an innovative approach to implementing integrated environmental and health and safety management systems in construction companies. It focuses on the sub-system for operational control of on-site environmental impacts and health and safety risks. The high compatibility between the operational control requirements that are stated in ISO 14001:2004 and OHSAS 18001:2007 and the demonstrated interactions between environmental impacts and health and safety risks (Gangolells et al., 2009, Gangolells et al., 2010) led us to develop a domain ontology to build an integrated knowledge model for operational control at construction sites. The ontology-based approach that we have developed is strongly influenced by the methodology provided by Noy and McGuinness (2001) and models the key concepts and their relations in the domain in a structured, extendable, flexible, reusable and shareable way. The ontology-based approach is implemented through Protégé 3.4 beta and properly evaluated by means of competency questions, internal verifications and expert validation interviews. This paper represents the first attempt at representing, sharing, reusing and managing the knowledge related to on-site integrated operational control of environmental and health and safety incidences and lays the ground for overcoming some barriers that contractors must face when they implement an integrated management system.

Keywords: Ontology, environmental impact, health and safety risk, integrated operational control, integrated management system, building, construction process

Resumen

Este artículo tiene como objetivo favorecer la implementación de sistemas integrados de gestión ambiental, de seguridad y salud en empresas constructoras, centrándose en el subsistema de control de los impactos ambientales y los riesgos de seguridad y salud en obra. La gran compatibilidad que presentan los requerimientos vinculados al control operacional establecidos en las normas ISO 14001:2004 y OHSAS 18001:2007 así como las interacciones existentes entre impactos ambientales y riesgos de seguridad y salud (Gangolells et al., 2009, Gangolells et al., 2010) han motivado el desarrollo de una ontología que permite construir un modelo integrado para el control operacional en obras de construcción. El enfoque desarrollado está fuertemente influenciado por la metodología de Noy y McGuinness (2001) y modela los conceptos clave y las relaciones del campo de forma estructurada, extensible, flexible, reutilizable y compatible. Este enfoque basado en ontologías ha sido implementado mediante Protégé 3.4 beta y correctamente evaluado utilizando preguntas de competencia, verificaciones internas y entrevistas de validación con expertos. Este artículo desarrolla el primer enfoque que permite representar, compartir, reutilizar y gestionar el conocimiento relacionado con el control operacional integrado en obra de las incidencias medioambientales, de seguridad y salud y sienta las bases para poder superar la mayoría de las barreras que las empresas constructoras deben afrontar durante el proceso de implementación de un sistema de gestión integrada.

Palabras Clave: Ontología, impacto ambiental, riesgo de seguridad y salud, control operacional integrado, sistema integrado de gestión, edificación, proceso constructivo.

1. Introduction

Many organizations have adopted or are adopting formal management systems based on standards such as ISO 9001, ISO 14001 and OHSAS 18001. However, these systems have been widely criticized for being bureaucratic, arduous, paper-driven and of questionable value to construction management (Griffith et al., 2000). In addition, research has demonstrated that the implementation and operation of the standards in parallel requires many duplicate management tasks (Labodová, 2004;

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Zeng et al., 2007). The difficulty of operating multiple parallel management systems at the same time (Zeng et al., 2007) and the increased compatibility between the different standards (Jørgensen et al., 2006) have led to the idea of integration. Research conducted to date on the most common obstacles encountered by organizations during the implementation of an integrated management system highlights a lack of technical guidance (Zeng et al., 2007; Zeng et al., 2005; Zutshi, 2005; Salomone, 2008; Tam et al., 2008). According to empirical studies reported by several authors, one issue that involves a high level of uncertainty during the adoption of an integrated management system is the integration of elements that correspond to the identification, evaluation and control of environmental impacts and health and safety risks (Salomone, 2008; Pheng and Shiua, 2000; Seiffert, 2008). Gangoellés et al. (2009), Gangoellés et al. (2010) and Gangoellés et al. (2011) presented a methodology allowing the integrated identification and evaluation of environmental impacts and health and safety risks in new-start residential construction projects. This paper goes one step further and explores an innovative approach to promoting the implementation of integrated environmental and health and safety management systems in construction companies through integrated operational control of on-site environmental impacts and health and safety risks in new-start residential construction projects.

The aim of this paper is to develop a formal approach to conceptualizing, organizing and formalizing knowledge related to the domain of on-site integrated environmental and health and safety management by developing an ontology-based approach. Through an ontology-based approach it is possible to identify key concepts in the domain and to define their relations in a consistent, extendable and understandable manner. Firstly, we present an introduction to on-site operational control according to ISO 14001:2004 and OHSAS 18001:2007. After providing a brief introduction to ontologies, Section 3 describes an ontology-based approach for on-site integrated environmental and health and safety management, using risk as an integrating factor (risk for the environment and risk for the health of on-site workers and the surrounding population). Section 4 describes the process of validating the ontology-based approach. Finally, we summarize the main conclusions of the research and discuss some future directions in Section 5.

2. Operational control

In reference to operational control (Figure 1), both ISO 14001:2004 and OHSAS 18001:2007 are focused on risk prevention and explicitly state that it is essential to identify processes and activities that could have a significant environmental impact or involve a significant health and safety risk and that are relevant to an organization's policies, objectives and targets. Both standards also state that an organization must plan its activities, including maintenance, to ensure that they are carried out under specified conditions by (1) establishing and maintaining documented procedures when their absence could lead to deviations from the policy, objectives and targets,

and (2) stipulating operating criteria in the procedures, among other factors.

Figure 1. General requirements for an integrated environmental and health and safety management system. Source: adapted from OHSAS 18001:2007 and ISO 90001:2008

If we consider that environmental impacts and health and safety risks are central features within the operational control domain, construction processes represent the link back to their 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 their corresponding relations configure the basis for efficient on-site integrated operational control.

From the research results described in Gangolells et al. (2009) and Gangolells et al. (2010), we can conclude that some of the risks of the construction process apply to the environmental and health and safety domains. Likewise, the documents that describe the work process of each construction operation (documented procedures) may also apply to both the environmental and the health and safety domains. Therefore, documented procedures can also be managed in an integrated way. A reduction in the duplication of procedures by combining the two systems could significantly reduce the overall size of the resulting management system and, more importantly, improve system efficiency and effectiveness.

A practical example of the benefits of integration is a welding procedure that describes the environmental requirements, the kind of health and safety rules that apply and the equipment the employee has to use. Noise or dust emissions at a construction site are hazards that should be reduced for the health and safety of the construction workers. However, this effort will also provide an environmental improvement. Undoubtedly, integrated operational control can also highlight trade-offs in a single domain. Any on-site instruction focusing on water saving by reusing rainwater will obviously reduce the environmental impact of water consumption during the construction process.

However, it may also simultaneously worsen the environmental impact of land occupancy by the building, provisional on-site facilities and storage areas. In the health and safety domain, on-site work instructions for using ear protection headphones will clearly mitigate safety risks related to the generation of noise and vibrations due to site activities, but may increase the risk of being hit or run over by vehicles, as headphones may prevent workers from hearing audible warnings from construction vehicles and machinery. Integrated operational control can also underline potential conflicts between the environmental and health and safety domains. For example, an on-site work instruction such as provisional masonry closures to prevent falls between different levels clearly has a negative effect on the environmental impact of raw materials consumption during the construction process. Similarly, any work instruction related to selective waste management will have a positive consequence by minimizing environmental impacts in the category of waste generation, but it may also increase the risk of injuries from being hit or run over by vehicles.

In this context, the development of an ontology-based approach was considered suitable, as ontologies have traditionally helped to effectively represent key concepts and their relationships in a particular subject area. Therefore, on the basis of the successful applications of ontology to other fields, the following subsection develops an ontology-based approach to gaining a better understanding of on-site integrated environmental and health and safety operational control.

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

There is no universally agreed definition of ontology, but one that is frequently cited is that given by Gruber (1993), who defined ontology as 'an explicit specification of a conceptualization'. According to Tserng et al. (2009), ontology can also be referred to as an explicit formal specification of the concepts in a specific domain and the relations among them. Ontologies are considered useful because they bring structure to knowledge about a subject area and make it explicit (Darlington and Culley, 2008). Therefore, ontologies become a basis for problem solving, effective communication, knowledge management and knowledge sharing. Experts often stress that there is no correct way to model a domain. The best solution almost always depends on the application that the ontology developer has in mind and the anticipated extensions (Noy and McGuinness, 2001).

3.1 Methodology

This research adopts the methodology provided by Noy and McGuinness (2001), as it was considered the clearest and most accessible methodology for domain specialists who have little or no prior knowledge of ontologies (Darlington and Culley, 2008). Figure 2 illustrates the main steps in this methodology:

Figure 2. Methodology for ontology development. Source: partially adapted from Noy and McGuinness (2001)

3.1.1 Determining the domain and scope of the ontology

According to Noy and McGuinness (2001), answering the following questions can help to establish the domain of the ontology:

- Which domain of interest will the ontology cover?
- The domain of interest is made up 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.
- What will the ontology be used for?
- The purpose of the ontology-based approach is to provide a context of knowledge that can assist in raising and answering all the appropriate questions for establishing a well-defined framework for integrated on-site environmental impacts and health and safety hazard control.
- Who will use the ontology?
- The ontology-based approach could be used as a guidance tool for contractors to effectively manage on-site environmental impacts and health and safety risks highlighted by the methodology developed in Gangoelle et al. (2009), Gangoelle et al. (2010) and Gangoelle et al. (2011) during the pre-construction stage. Therefore, after its implementation in a web-based system, the ontology-based approach could be used during construction works by site managers, health and safety officers and environmental officers.

According to Noy and McGuinness (2001), one of the ways to determine the scope of an ontology is to sketch a list of questions that it 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:

- Which environmental impacts and health and safety risks are typically related to the construction of a residential building?
- Which construction processes may cause a particular environmental impact or health and safety risk?
- Which environmental impacts and health and safety risks are related to a particular construction process?
- Does a particular risk apply simultaneously to the environmental and health and safety domains?
- Which 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?
- Which implemented work instructions may be tangentially beneficial or detrimental to a particular environmental impact or health and safety impact?
- Which environmental impacts and health and safety risks are reduced, tangentially increased or tangentially decreased by implementing a particular work instruction?

3.1.2 Considering the reuse of existing ontologies

We accessed several ontology libraries because one of the factors that drive the development of ontologies is the idea of knowledge reuse and shareability (Darlington and Culley, 2008). Unfortunately, neither the Ontolingua library (KSL, 2010) nor the DAML library (DAML, 2010) included reusable ontologies for the on-site environmental and health and safety management domain. We also reviewed several research projects within the construction field, such as the e-CONSTRUCT project (Electronic Communication in the Building and Construction Industry: Preparing for the New Internet; IST-1999-10303) and the e-COGNOS project (COnsistent knowledGe maNagement across prOjects and between enterpriSes in the construction domain; IST-200-28671), but they did not include useful ontologies for the abovementioned purpose. We also revised the existing scientific literature and we found that ontologies have mostly been applied to support information and knowledge management systems within the construction industry (Anumba et al. 2008b), such as the approaches provided by Anumba et al. (2002), El-Diraby et al. (2005), Issa and Mutis (2006), Anumba et al. (2008a), Yurchyshyna and Zarli (2009) and El-Gohary and El-Diraby (2010). 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, such as the approaches provided by Staub-French et al. (2003) and Edum-Fotwe and Price (2009).

In other papers, ontologies are reported to support decision-making during the design process, such as in Garcia et al. (2004), Pandit and Zhu (2007), Ugwu et al. (2005) and Skolick and Kicingier (2002). As the present study focuses on the on-site environmental and health and safety management domain, none of the existing ontologies were found to be useful. Darlington and Culley (2008) argue that the number of existing and available formally represented ontologies is currently minimal when compared with the subject matter that is potentially available for formalization (the entire conceptual world). Consequently, when we look for a suitable ontology, we may not be able to find one that relates to the current area of formalization (Darlington and Culley, 2008).

3.1.3 Enumerating important terms

This step consists of two tasks: (1) identification of the key concepts and relationships in the domain of interest and (2) production of unambiguous text definitions for such relationships (Darlington and Culley, 2008). As stated in section 2 and according to the requirements in ISO 14001:2004 and OHSAS 18001:2007 under the subsection of operational control, environmental impacts, health and safety risks, construction processes and work instructions are identified as crucial for integrated operational control:

- *Environmental impacts: according to ISO 14001:2004, environmental impacts are defined as any adverse or beneficial changes to the environment that wholly or partially result from an organization'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: according to the Project Management Institute (2009), a process is defined 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 research as a set of interrelated actions and activities performed to achieve a construction entity, in this case, a residential building.*
- *Work instructions: according to 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 are therefore often supported by detailed work instructions, which contain the exact process for performing the function.*

3.1.4 Defining the classes and the class hierarchy

According to Noy and McGuiness (2001), classes describe concepts that exist independently 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.

Previous researchers have argued that it is always worth considering the reuse of existing controlled vocabularies (ontologies, taxonomies or thesauruses). For this reason, we carried out an exhaustive search of several controlled vocabularies in the construction domain (Lima et al., 2007), including ISO 12006-2:2001, Industry Foundation Class (IFC), 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 the Standard Dictionary for Construction (Gencod EAN, France). Other initiatives include Industry Foundation Classes (the International Alliance of Interoperability), the Canadian Thesaurus of Construction Science and Technology (National Research Council, Canada), the Construction Management Standards of Practice (the Construction Management Association of America), the MACE Taxonomy (Metadata for Architectural Contents in Europe), and the Content Thesaurus on subterranean works (La Ciudad Multidimensional). Unfortunately, the main disadvantage of all these semantic resources is that they do not include on-site environmental and health and safety management-related terms or they are not concise enough. However, other controlled vocabularies in the environmental or health and safety domains are not sufficiently focused on the construction sector. In some specific cases, controlled vocabularies are related to construction safety, but they are not wide enough to cover health and safety risks related to the construction process and on-site safety work instructions. Similarly, some semantic resources focus on sustainable construction, but they do not cover the environmental impacts of 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. Each major class has related subclasses and even sub-subclasses. A subclass of a class represents a concept that is 'a kind of' the concept that the superclass represents. Accordingly, to ensure the correct definition of subclasses and sub-subclasses, all the subclasses of a class were checked to ensure that they had an 'is a' relation with their class.

a) Construction Processes

ISO 12006-2:2001 states that particular classification systems that meet regional or national requirements can be developed according to a common international approach. Therefore, this research adopted as construction processes the work sections provided by the Catalan Institute of Construction Technology (ITeC) within the MetaBase database (ITeC, 2006). There are two main reasons for this decision. Firstly, environmental impacts and health and safety risks related to the construction process were obtained by means of a process-oriented approach (Gangolells et al., 2009; Gangolells et al., 2010). In both cases, the construction stages and activities that were taken into consideration were those work sections provided by the ITeC within the MetaBase database (ITeC, 2006). Secondly, the MetaBase database (ITeC, 2006), which includes reference prices for work sections, is the information source that has been most widely used by official and private entities (designers and contractors) in Catalonia since 1985.

Figure 3 illustrates part of the 286 classes, subclasses and sub-subclasses related to the major class 'Construction processes'.

Figure 3. Classes and class hierarchy for 'Construction Processes'. Source: partially adapted from ITeC (2006)

b) Environmental Impacts

In this case, the 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, a top-down approach was used, since the environmental impacts of the construction process were obtained from standardized generic environmental impacts. This approach, which is described in Gangolells et al. (2009), meant that we could obtain the classes and class hierarchy within the major class 'Environmental Impacts' (Figure 4). In this case, 46 classes, subclasses and sub-subclasses were considered within the major class of 'Environmental Impacts'.

Figure 4. Classes and class hierarchy for 'Environmental Impacts'. Source: partially adapted from Gangolells et al. (2009)

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 (Gangolells et al., 2010). 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' (Figure 5). Finally, a set of 116 classes, sub-classes and sub-subclasses were obtained within the major class 'Health and Safety Risks'.

Figure 5. Classes and class hierarchy for 'Health and Safety Risks'.

Source: partially adapted from Gangolells et al. (2010)

Some of the risks were found to 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'. The generation of noise and vibrations due to site activities, which are classified into the environmental category of 'local issues', also fit the safety category of 'contact with physical agents'. All the environmental aspects related to incidents, accidents and potential emergency situations also correspond to risks in the safety domain, specifically in the 'fires and explosions' category.

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 literature review, and an analysis of a sample document (Tserng et al., 2009). Since we did not find any controlled vocabularies in the existing literature that covered on-site work instructions, we used 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 (Gremio de Constructores de Obras de Barcelona y Comarcas, 2007) and the on-site safety work instructions published by the Government of Catalonia (Construcciones Rubau et al., 2007). In both cases, the on-site work instructions were developed by a panel of experts. Therefore, it can be assumed that they are comprehensive and rigorous enough to configure the right knowledge database for concept extraction. Selected reference documents were thoroughly analysed to identify words with a relevant meaning within the domain. Through this extraction method, the 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 synonymous concepts into a single concept. Finally, a set of approximately 300 classes, sub-classes and sub-subclasses emerged (Figure 6).

Figure 6. Classes and class hierarchy for 'Work Instructions'. Source: own elaboration

3.1.5 Defining the properties of classes

According to Noy and McGuinness (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 focused on generating a set of relationships (or properties) that showed a structural representation of the identified classes. A property is attached to the most general class that can have that property. All the subclasses of a class inherit the property of that class. Figure 7 illustrates the conceptual structure that defines the interactions between the various concepts in the problem domain:

Figure 7. Conceptual structure showing the relationships between major classes in the ontology-based approach for on-site integrated environmental and health and safety management. Source: own elaboration.

Thus, the following properties have been defined:

- The relationship 'takes place in' relates 'Health and Safety Risks' and 'Environmental Impacts' to the corresponding 'Construction Processes'. Each health and safety risk / environmental impact takes place during one or more construction processes. The relationship 'origins' is the inverse relation of 'takes place in'.
- The relationship 'reduces' relates 'Work Instructions' to the corresponding 'Health and Safety Risks' and 'Environmental Impacts'. Each work instruction may reduce one or more health and safety risks / environmental impacts. The relationship 'is reduced by' is the inverse of 'reduces'.

- The relationship 'affects positively' relates 'Work Instructions' to corresponding 'Health and Safety Risks' and 'Environmental Impacts'. Although not implemented for this purpose, a work instruction may positively affect one or more health and safety risks / environmental impacts. The relationship 'is affected positively' is the inverse of 'affects positively'.
- The relationship 'affects negatively' relates 'Work Instructions' to corresponding 'Health and Safety Risks' and 'Environmental Impacts'. Although not implemented for this purpose, a work instruction may affect one or more health and safety risks / environmental impacts negatively. The relationship 'is affected negatively' is the inverse relation of 'affects negatively'.

Both the relationship 'takes place in', which relates 'Health and Safety Risks' and 'Environmental Impacts' to the corresponding 'Construction Processes', and its inverse relationship 'origins' were obtained by means of a process-oriented approach (Gangolells et al., 2009; Gangolells et al., 2010). Other relationships that relate 'Work Instructions' to the corresponding 'Health and Safety Risks' and 'Environmental Impacts' were specifically derived to take into account the purpose of the ontology-based approach for on-site integrated environmental and health and safety management with the help of a panel of experts. Finally, more than 6100 relationships were included within the ontology-based approach for on-site integrated environmental and health and safety management.

3.1.6 Creating instances of classes

According to Noy and McGuinness (2001), the last step is to create individual instances of classes in the hierarchy. To define an individual instance of a class, we must choose a class, create an individual instance of that class and fill in the specific property values. In this case, for the purpose of this study no instances needed to be created. Instances should only be created in the case of a particular construction company that uses the developed ontology-based approach for on-site integrated environmental and health and safety management and has its own procedures and on-site work instructions. In this case, a particular on-site work instruction that already exists in the construction company could be an instance of the corresponding subclass or sub-subclass of the ontology. The creation of instances of classes allows work instructions that already exist in any construction company to be semantically matched to the developed classes and subclasses, which allows the ontology to be universalized.

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

To validate the ontology-based approach, we carried out two preliminary activities. First, verifications were made by checking whether the information was available in the ontology-based approach and whether the right relations existed. Secondly, according to suggestions in the existing literature, competency questions were used to validate the ontology-driven solution. The ontology-based approach for on-site integrated environmental and health and safety management was found to be able to answer the competency questions that were initially defined (see Section 3.1.1). Therefore, at this stage, the conceptual structure was considered reasonable and correct for its intended purpose.

The ontology-based approach for on-site integrated environmental and health and safety management was implemented through Protégé 3.4 beta, the most widely used tool for extending and sharing ontologies in a broad range of knowledge domains. This open-source editor facilitates the visualization of ontology-driven solutions and allows easy management of classes, subclasses, sub-subclasses and the corresponding relations. The implementation of the solution in Protégé 3.4 beta allowed us to verify the robustness and consistency of the proposed approach.

Finally, once the computerized version of the ontology-based approach had been correctly verified, an external evaluation was carried out by three domain experts, all of whom had PhDs in construction engineering. In the first stage, to assure ease of navigation, the experts were asked to find four concepts in the application. Based on the results, we can conclude that the ease of navigation of the ontology-based approach is acceptable.

Secondly, the experts were asked to check whether the ontology-based approach could answer the pre-defined competency questions. However, the competency questions had to be customized to make the external evaluation easier. After this validation activity, we concluded that the ontology-based approach showed all the environmental impacts and health and safety risks that are typically related to the construction process of a residential building (Figure 8 and 9). We also certified that the ontology-based approach illustrates the construction processes in which a particular environmental impact or health and safety risk occurs and its inverse relations (the significant environmental impacts and health and safety risks that take place as a consequence of performing a particular construction process) (Figure 10). This validation activity also allows us to state that the ontology-based approach can show whether a particular risk is simultaneously applicable to the environmental and the health and safety domains (Figure 11).

According to the experts, for each environmental impact or health and safety risk, the ontology-based approach illustrates which work instructions may be implemented to reduce its significance (Figure 12). The ontology-based approach also shows how work instructions that are implemented to diminish the significance of a particular environmental impact or health and safety risk may positively or negatively affect the significance of other environmental impacts or health and safety risks. Finally, it was found that the ontology-driven solution also shows the environmental impacts and health and safety risks that were reduced, tangentially increased or tangentially decreased as a result of implementing a particular work instruction (Figure 13). Results obtained during this validation activity enabled us to conclude that the ontology-based approach was reasonable and correct for its intended purpose.

Finally, interviews were held with the domain experts to assure the potential applicability of the proposed ontology-based approach. The experts did not make any major comments on this issue and the general assessment of the ontology-based approach for on-site integrated environmental and health and safety management was positive.

Figure 8. Relationship between the category 'Local Issues' and 'Environmental Impacts'

Figure 9. Relationship between the category 'Contact with Physical Agents' and 'Health and Safety Risks'

Figure 10. Identification of environmental impacts and health and safety risks related to the construction process 'demolitions, earthworks and waste management: soil and inert waste loading'

Figure 11. Available information related to the environmental impact / health and safety risk L-2 (dust generation in earthwork activities and stockpiles)

Figure 12. Identification of work instructions related to the environmental impact / health and safety risk L-2 (dust generation in earthwork activities and stockpiles)

Figure 13. Identification of environmental impacts and health and safety risks related to the work instruction 'instructions for using crushers'

5. Conclusions

This study takes an essential step in formalizing the theoretical framework needed to enhance the implementation of integrated environmental and health and safety management systems in construction companies through integrated operational control. The main outcome is to provide an innovative approach for clarifying and representing the knowledge related to on-site integrated environmental and health and safety operational control through the development of an ontology-based approach.

The ontological map allows us to gain a better understanding of practical considerations of on-site environmental and health and safety management, and to systematically consider the relation between construction processes, environmental impacts, health and safety risks and work instructions. Representing and managing the structure of knowledge related to integrated on-site environmental and health and safety management enables knowledge sharing and reuse among domain experts and the stakeholders who are simultaneously involved in a construction site. The ontology-based approach may also help to address the existing dichotomy between tacit and explicit knowledge. The ontology-based approach identifies the on-site work instructions that should be implemented to either avoid a possible environmental impact or health and safety risk before it occurs or minimize its negative effect when it does take place. The strength of the solution lies in the fact that potential inferences are highlighted. Thus, the effect of any particular on-site work instruction on the whole set of environmental impacts and health and safety risks is included within the approach. Another key feature of the ontology-based approach is the identification of when corresponding on-site work instructions should be implemented. This is achieved by reviewing the list of related construction processes in which the incident may take place. The ontology-based approach also relates the environmental impacts and health and safety risks that take place during a particular construction process.

Future studies should implement the ontology-driven solution in a web-based system. The implementation of this approach in a friendlier environment would offer handy guidance to contractors on the integrated management of many of the environmental and health and safety incidences at the construction site. In this case, the ontology-based approach for on-site integrated environmental and health and safety management could be used as a framework for contractors to effectively manage environmental impacts and health and safety risks during the construction of their projects, and to provide support in particular on the implementation of necessary control measures to lower health and safety risks and environmental impacts to an acceptable level. To enhance future knowledge reuse and shareability, the ontology-based approach for on-site integrated environmental and health and safety management could be linked to existing validated ontologies or taxonomies within the construction domain. Complete mapping could be executed by establishing proper relationships between concepts that are already included in validated standards for 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 ontology-based approach into other ontologies that are based on validated standards.

6. Referencias/References

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