KNOWLEDGE MOBILIZATION TO SUPPORT ENVIRONMENTAL IMPACT ASSESSMENT
A Model and an Application

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Abstract: EIA is a complex problem due to the wide range of different human impacts, the amount of different environmental indicators to measure the effect of an impact, and the correlation among them. In this paper we propose an application to support knowledge mobilization in Environmental Impact Assessment (EIA) based on a formal model to represent relevance between context descriptions and domain-knowledge subsets. The CDS (Context-Domain Significance) pattern allows building a tool to assist in the data collection phase to establish the relevant indicators in a particular scenario.

1 INTRODUCTION

Knowledge Mobilization comprises all the efforts aimed to take advantage of the features provided by mobile networks and devices in order to improve Knowledge Management procedures. The mobilization of knowledge consists of making "knowledge available for real-time use in a form which is adapted to the context of use and to the needs and cognitive profile of the user" (Keen and Mackintosh, 2001). In other words, Knowledge Mobilization should furnish users with suitable knowledge to support decision-making wherever they are located.

From a pragmatical point of view, Knowledge Mobilization addresses the challenge of developing Knowledge Mobilization Systems, which are ubiquitous, proactive, declarative, context-aware, integrative, and concise (Gómez-Romero, 2008). Several theories and technologies, most of them from Intelligent Systems and Soft Computing areas, have been proposed to accomplish mobilization. Among them, Semantic Web and Ontologies play a crucial role in building knowledge (Perttunen et al., 2009).

Knowledge management is especially relevant in application domains affected by information overload. Information overload is described as a situation in which a user is provided with more data than he can digest, either because sifting through the information received would take too much time or simply because interesting facts cannot be separated from irrelevant data (Eppler and Mengis, 2004). Knowledge Mobilization systems must rely on suitable representations that take into account what is significant or relevant to the user, which depends on certain factors other than the query to be solved: environment, preferences, previous actions, etc. All these pieces of information, used to characterize the situation of the entities, can be regarded as *context* (Dey and Abowd, 2000), and the results of the query must be adapted to it.

Accordingly, a Knowledge Mobilization system must include two kinds of knowledge in its supporting ontologies: (i) knowledge specific of the domain of the application; (ii) knowledge describing contextual situations. The significance of a piece of domain-specific information in a given context is represented by a relation between an ontological description of the situation and an ontological definition of the domain knowledge.

There are some approaches in the literature aimed at the creation of ontologies representing this notion of context-dependent significance. This is the case of the Context-Domain Significance (CDS) pattern (Bobillo et al., 2008). This ontology design pattern defines a set of rules to build a new ontology compliant to the OWL standard (McGuiness and van Harmelen, 2004) where context descriptions and domain expressions are connected through constrained relations. The main reasoning task within a CDS ontol-

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ogy is to retrieve the pieces of domain-specific knowledge that are significant in a given context.

In this paper, we study how the CDS model can be applied in an Environmental Impact Assessment (EIA) application to overcome mobilization issues. EIA is a systematic process to assess the actual or potential effects of human policies, objectives, programs, plans, or activities on the local or global environment. Thus, an EIA study analyzes a complex system with several factors difficult to understand due to its large volume and the relationships among themselves. For example, determining how a road route can affect an ecosystem, or an industrial activity might affect the birds or an indigenous specie of worm. The CDS model allows the summarization of the number of factors that should be considered by the auditor, according to the available extra information about the environment analyzed and the purpose of the study. We present a Knowledge Mobilization system prototype for EIA based on the CDS that facilitates the labour of environmental experts by simplifying data collection procedures and adding detailed annotations to this information.

The paper is structured as follows. In Sect. 2, we discuss some research works on the development of knowledge-based solutions to EIA. In Sect. 3, we describe the use of the CDS ontology-design pattern to develop the knowledge base of our application, as well as the functioning of the algorithm to retrieve significant knowledge from context descriptions. Section 4 describes the implementation and a use case of the Knowledge Mobilization system. The paper ends with some conclusions and plans for future work.

2 RELATED WORK

Environmental applications require the participation of a large amount of information sources, which makes convenient the use of proper representation formalisms. Different approaches to knowledge-based environmental tools and models have been developed in the last years. These contributions incorporate formal knowledge representations in their data model, and, specifically, ontologies.

OntoWEDSS is a decision-support system for wastewater management. OntoWEDSS extends classic rule-based reasoning and case-based reasoning with a domain ontology, which results in more flexible management capabilities. The ontology models the treatment process, provides a shared and common vocabulary, and improves the communication among different elements and agents of the system (Ceccaroni et al., 2004).

The SEEK project[1] aims at the development of an infrastructure to support the whole process of ecological and biodiversity data management, from the acquisition stage to the synthesis and integration stage. SEEK implements a semantic mediation module, which is an advanced reasoning system that can determine whether relevant data should be automatically transformed for use with a selected workflow. The Extensive Observation Ontology (OBOE) framework has been developed in the context of the SEEK project (Madin et al., 2007). OBOE includes an ontology for describing and synthesizing ecological observational data. The framework allows capturing the process of ecological field observation and measurement, facilitating logic-based reasoning and making it possible data discovery, summarization, and integration processes. A previous environmental ontology is Ecolingua, which aims at representing ecological quantitative data (Brilhante, 2004).

In (Oprea, 2005), the authors present a knowledge-based system that addresses the problem of air pollution control decision support. In (Batzias and Siontorou, 2006), a decission support system for bio-monitoring is described. This system uses a bio-indicator ontology of environmental exposure that links pollution to morphological response and biochemical alterations. In (Chau, 2007), the authors develop an ontology-based system for assisting engineers in the management of knowledge about flow and water quality. The system aims at simulating the behavior of human experts in problem solving by using descriptive, procedural, and reasoning knowledge. The problem of model-based water management is also faced in (Scholten et al., 2007). These authors have implemented an ontology-based tool that supports the simultaneous treatment of two or more domains as an integrated domain (multidomain approach). The SOLERES project is a spatial-temporal information system for environmental management and automatic generation of ecological maps from satellite images. SOLERES is based on a knowledge representation module used to model the environmental information (Padilla et al., 2008).

3 DEVELOPMENT OF THE CONTEXT-DEPENDENT ONTOLOGY FOR EIA

In this section, we will explain how the CDS pattern is applied to build the supporting ontology of the

[1] http://seek.ecoinformatics.org

knowledge mobilization system for EIA-assistance. Essentially, the CDS pattern defines how to build a new OWL ontology where concepts representing contextual situations and concepts representing domain knowledge are connected through relations. We will exemplify how to create context descriptions, domain expressions, and relations in the EIA domain.

The new ontology is used to retrieve all the concepts in the domain ontology which ought to be considered in a given context. The CDS pattern provides a suitable algorithm to perform this operation based on the execution of various basic DL inference tasks. We will show the functioning of the algorithm with an example in the EIA application.

For a comprehensive description of using and reasoning with the CDS pattern, we refer the reader to (Bobillo et al., 2008). We refer the reader unfamiliar with Description Logics formalisms and the OWL language to the book edited by (Baader et al., 2003).

3.1 Knowledge Base Development

A CDS ontology[2] is built from two basic sub-ontologies, one representing domain-specific knowledge and another defining a vocabulary to describe context situations. The *domain-specific ontology* ($\mathcal{K}^D$) contains the knowledge required to solve the concrete problem that the system is facing. The *context ontology* ($\mathcal{K}^C$) contains the knowledge required to describe situations that determine which information of the domain is relevant. The *significance ontology* ($\mathcal{K}^S$) is a new ontology where complex contexts, complex domains, and links between them are defined.

Domain Ontology. In EIA, the domain ontology abstractly represents the information that the auditor has to collect, i.e., the indicators required by an environmental assessment methodology. An indicator is a simple measurement of environmental factors or biological species that are representative of the characteristics of a biophysical system. That is, indicators provide interesting measures about the state of the whole ecosystem or a specific part. Indicators, represented as instances of the subclasses of the concept `Indicator`, have been collected from specialized literature (Garmendia et al., 2005; Barettino et al., 2005). A comprehensive description of the indicators used is out of the scope of this paper –the ontology domain contains currently seventy six different indicators.

Companies, represented as instances of the concept `Company`, may have related several environmental assessments developed as a result of their activities. Environmental assessments are stored as instances of the concept `EIA`. The object property `hasEIA` relates companies and EIAs. An `EIA` instance represents a set of indicator measures in a given period of time. `EIA` instances and `Indicator` instances are related with the object property `hasMeasurement`.

From the indicators ontology, complex domain expressions can be built. These new concept definitions built from elements of the domain-specific ontology and ontology concept constructors are called complex domains (noted as D_j). For example, the complex domain $\mathtt{D_1} \equiv \mathtt{GroundwaterQuality} \sqcup \mathtt{BiodiversityIndex}$ represents a set including indicators about water quality and biodiversity.

Context Ontology. The context knowledge, in turn, correspond to the possible activities that cause the development of the EIA process. Depending on the type of activity, the auditor focuses on different indicators. Thus, the context ontology establishes a vocabulary to describe activities from human actions, places, and installations. For example, concepts of the context ontology are `Agriculture` and `WaterExtraction`, which are hazardous activities.

New concept definitions built from elements of the context ontology and ontology concept constructors are called complex contexts (noted as C_i). For example, an agrarian cultivation which uses irrigation, fertilizers, and treatments for insects is represented with the complex context $\mathtt{C_1} \equiv \mathtt{Agriculture} \sqcap \mathtt{FertiliserTreatment} \sqcap \mathtt{Irrigation} \sqcap \mathtt{PesticideTreatment}$.

It is important to notice that D_j and C_i are not part of the domain and the context ontology, respectively. As mentioned, these ontologies provide a vocabulary to build more complex concepts, which may not be defined in these ontologies.

[2]We note an ontology as a triple $\mathcal{K} = \langle \mathcal{T}, \mathcal{R}, \mathcal{A} \rangle$, where $\mathcal{T}$ (the TBox) and $\mathcal{R}$ (the RBox) contain, respectively, axioms about concepts and roles (terminological axioms), and $\mathcal{A}$ (the ABox) contains axioms about individuals (asserts). The symbols used in $\mathcal{K}$ are its signature or vocabulary. Formally, the signature is the disjoint union $\mathbf{S} = \mathbf{C} \uplus \mathbf{R} \uplus \mathbf{I}$, where $\mathbf{C} = \{A\}$ is the set of atomic concepts (or classes); $\mathbf{R} = \{R_A\}$ the set of atomic roles (or properties); and $\mathbf{I} = \{a, b, \ldots\}$ the set of individuals (or instances). From the atomic elements in $\mathbf{S}$, new complex concepts $\mathsf{Con}(\mathbf{S}) = \{C_{(i)}, D_{(i)}, \ldots\}$, roles $\mathsf{Rol}(\mathbf{S}) = \{R_{(i)}\}$, and axioms $\mathsf{Ax}(\mathbf{S}) = \{O_{(i)}\}$ can be composed (subscripts are not used when disambiguation is not needed). By extension, the signature $\mathbf{S}(O)$ of an axiom (respectively for roles and concepts) is the set of atomic elements of $\mathbf{S}$ which are included in O (respectively R and C). The signature of an ontology $\mathbf{S}(\mathcal{K})$ is the union of all the signatures $\mathbf{S}(O)$ of the axioms in $\mathcal{K}$.

Table 1: Example of CDS knowledge model.

When agricultural activities involving pruning processes are going to be developed, it is necessary to check the index of biodiversity, soil humidity and vegetal coverage.

$\mathtt{C_1} \equiv \mathtt{Agriculture} \sqcap \mathtt{Pruning}$
$\mathtt{D_1} \equiv \mathtt{BiodiversityIndex} \sqcup \mathtt{SoilHumidity} \sqcup \mathtt{VegetalCoverage}$
$\mathtt{P_{1,1}} \equiv \exists \mathtt{hasAction.C_1} \sqcap \exists \mathtt{hasIndicator.D_1}$

When agricultural activities involving pruning processes and burning of its remainders are going to be developed, it is necessary to check the index of biodiversity, soil humidity and vegetal coverage, and the affected area by smells.

$\mathtt{C_2} \equiv \mathtt{Agriculture} \sqcap \mathtt{Pruning} \sqcap \mathtt{Burning}$
$\mathtt{D_2} \equiv \mathtt{BiodiversityIndex} \sqcup \mathtt{SoilHumidity} \sqcup \mathtt{VegetalCoverage} \sqcup \mathtt{AffectedAreaBySmells}$
$\mathtt{P_{2,2}} \equiv \exists \mathtt{hasAction.C_2} \sqcap \exists \mathtt{hasIndicator.D_2}$

When agricultural activities involving groundwater extraction and sloped land divisions into terraces are going to be developed, it is necessary to check the index of biodiversity, soil humidity, vegetal coverage, soil loss and the alteration of the phreatic level.

$\mathtt{C_3} \equiv \mathtt{Agriculture} \sqcap \mathtt{WaterExtration} \sqcap \mathtt{TerraceControl}$
$\mathtt{D_3} \equiv \mathtt{BiodiversityIndex} \sqcup \mathtt{SoilHumidity} \sqcup \mathtt{VegetalCoverage} \sqcup \mathtt{SoilLossRates} \sqcup \mathtt{PhreaticLevelAlteration}$
$\mathtt{P_{3,3}} \equiv \exists \mathtt{hasAction.C_3} \sqcap \exists \mathtt{hasIndicator.D_3}$

When agricultural activities involving groundwater extraction, fertilizer use, insects and weeds control are going to be developed, it is necessary to check the affectation of groundwater quality, biodiversity, soil humidity, vegetal coverage, alteration of the phreatic level, and soil contents in metals and salts.

$\mathtt{C_4} \equiv \mathtt{Agriculture} \sqcap \mathtt{WaterExtration} \sqcap \mathtt{Fertilizer} \sqcap \mathtt{InsectsControl} \sqcap \mathtt{WeedsControl}$
$\mathtt{D_4} \equiv \mathtt{BiodiversityIndex} \sqcup \mathtt{SoilHumidity} \sqcup \mathtt{VegetalCoverage} \sqcup \mathtt{PhreaticLevelAlteration} \sqcup \mathtt{GroundwaterQuality} \sqcup \mathtt{ContentInMetal} \sqcup \mathtt{ContentInSalts}$
$\mathtt{P_{4,4}} \equiv \exists \mathtt{hasAction.C_4} \sqcap \exists \mathtt{hasIndicator.D_4}$

Significance Ontology. The significance ontology is the model where complex contexts C_i, complex domains D_i, and links between them are defined. These links, called σ-connections (connections representing *sig*nificance), state that the domain-specific knowledge D_j should be considered in situation C_i. In our case, a σ-connection establishes that a set of environment indicators must be measured or calculated when the impact of a set of human actions is evaluated.

A σ-connection concept is a new concept representing a σ-connection. It is defined with existential restrictions on the complex context and the complex domain that it links (via properties R_c and R_d). When there is no possibility of confusion, we use the term σ-connection instead of σ-connection concept.

$\mathcal{K}^S$ ontology is developed as follows:

Definition 1. *Let $\mathcal{K}^D$ and $\mathcal{K}^C$ be, respectively, the domain and context ontologies, C_i a complex context, and D_j a complex domain. The significance or CDS ontology that relates the set of pairs (C_i, D_j) is a consistent ontology $\mathcal{K}^S = \langle \mathcal{T}^S, \mathcal{R}^S, \mathcal{A}^S \rangle$ such that $\mathcal{T}^S$ (non-exclusively) includes definitions for the concepts $P_\top, C_\top, D_\top, C_i, D_j, P_{i,j}$, which satisfy:*

1. *$P_\top$, $C_\top$, $D_\top$ are the superclasses "σ-connection concePt', "complex Context" and "complex Domain":*
   - $P_{i,j} \sqsubseteq P_\top$, $C_i \sqsubseteq C_\top$, $D_j \sqsubseteq D_\top$
2. *R_c is the bridge property linking σ-connections and complex contexts:*
   - $P_\top \sqsubseteq \forall R_c.C_\top$
3. *R_d is the bridge property linking σ-connections and complex domains:*
   - $P_\top \sqsubseteq \forall R_d.D_\top$
4. *$P_{i,j}$ is the σ-connection linking the complex context C_i and the complex domain D_j:*
   - $P_{i,j} \equiv \exists R_c.C_i \sqcap \exists R_d.D_j$

In its definition, the CDS pattern assumes that the domain and the context ontologies are disjoint, since context usually encompasses external to the interest area. This is not our case and, without loss of generality, (non-complex) context and domain terms are included in the same ontology.

Table 1 shows a brief example of the CDS ontology for the EIA application. The bridge properties are $R_c \equiv \texttt{hasAction}$ and $R_d \equiv \texttt{hasIndicator}$. It can be observed that $\texttt{C}_2 \sqsubseteq \texttt{C}_1$, $\texttt{D}_2 \sqsubseteq \texttt{D}_1$ and, for the concept $\texttt{C}_5 \equiv \texttt{Agriculture} \sqcup \texttt{WaterExtraction}$, $\texttt{C}_3 \sqsubseteq \texttt{C}_5$ and $\texttt{C}_4 \sqsubseteq \texttt{C}_5$.

3.2 Reasoning

The main reasoning task involving a significance ontology consists in finding all the concepts in the domain ontology which ought to be considered in a given context. This is the significant domain for a context, and is formally defined as follows:

Definition 2. *Let $\mathcal{K}^D$ be a domain-specific ontology, $\mathcal{K}^C$ a context ontology, and $\mathcal{K}^S$ a CDS ontology, with their respective signatures $\mathbf{S}(\mathcal{K}^D)$, $\mathbf{S}(\mathcal{K}^C)$, and $\mathbf{S}(\mathcal{K}^S)$. Let $\mathsf{Con}(\mathcal{K}^D)$ be the set of composite concepts that can be built from the primitive concepts of $\mathcal{K}^D$. Let scenario E be a concept $E \in \mathbf{S}(\mathcal{K}^C)$.*

The domain knowledge in $\mathcal{K}^D$ that is significant in the scenario E w.r.t. $\mathcal{K}^S$, denoted as $\mathcal{D}(E, \mathcal{K}^S)$, is a set which includes the concepts I such that $\mathcal{D}(E, \mathcal{K}^S) = \{I \mid I \in \mathsf{Con}(\mathcal{K}^D) \wedge \mathcal{K}^S \models \{E \sqsubseteq C_n, P_{n,m} \sqsubseteq P_\top, I \sqsubseteq D_m\}\}$

Concepts in I can be retrieved by performing several subsumption tasks. Formally:

Algorithm 1: $\mathcal{D}(E, \mathcal{K}^S)$ can be computed in practice as follows.

1. $\{C_n\} = \{C_n \sqsubseteq C_\top \mid E \sqsubseteq C_n\}$
2. $\{P_{k,l}\} = \{P_{k,l} \sqsubseteq P_\top \mid (P_{k,l} \sqsubseteq \exists R_c.C_k) \wedge (C_k \equiv C_n)\}$
3. $\{D_m\} = \{D_m \sqsubseteq D_\top \mid (P_{k,l} \sqsubseteq \exists R_d.D_l) \wedge (D_m \equiv D_l)\}$
4. $\mathcal{D}(E, \mathcal{K}^S) = \{I \in \mathsf{Con}(\mathcal{K}^D) \mid I \sqsubseteq D_m\}$

As a matter of example, assuming the CDS model depicted in Table 1, let us suppose that we want to retrieve the indicators that are relevant in a scenario where the following actions are to be performed: `Agriculture`, `Pruning`, `Burning`, and `WaterExtraction`. This is accomplished by using Algorithm 1 to calculate the restricted domain of the complex context concept $E \equiv \texttt{Agriculture} \sqcap \texttt{Prunning} \sqcap \texttt{Burning} \sqcap \texttt{WaterExtraction}$.

1. $C_n = \{\texttt{C}_1, \texttt{C}_2\}$
2. $P_{k,l} = \{\texttt{P}_{1,1}, \texttt{P}_{2,2}\}$
3. $D_m = \{\texttt{D}_1, \texttt{D}_2\}$
4. $I = \{$`BiodiversityIndex`, `SoilHumidity`, `VegetalCoverage`, `AffectedAreaBySmells`$\}$

Accordingly, the significant indicators in this case would be those corresponding to the concepts included in I.

4 EIA-ASSISTANCE APPLICATION

The IASEIA application (*Intelligent ASsistant for Environmental Impact Assessment*) is a prototype of a Knowledge Mobilization system to support auditors to carry out EIA process. This application uses a CDS model developed according to the specifications and the examples presented in the previous section.

To create the model, we have used the CDS plugin for Protégé and the CDS API (Bobillo et al., 2008). The CDS plugin is a tool that allows knowledge engineers to create, edit, test and reason with a CDS ontology. The plugin adds a new tab to the Protégé-OWL environment where a user-friendly view of the CDS ontology is displayed and queries can be introduced. The CDS API is a Java library to programmatically manage models created with the CDS pattern. It includes methods to carry out the most common processes involving a CDS model: definition of complex contexts and domains, creation of profiles, retrieval of significant domain knowledge, etc. A beta version of these tools can be found in the web[3].

The architecture of IASEIA is depicted in Figure 1. It is divided into three parts: the client agent, the server agent, and the knowledge-data layer. The client agent allows the user to access to the application by using a standard web browser with an internet connection. Since reasoning and complex operations are accomplished in the server side, the device consumes little resources and the application works successfully with any common browser.

4.1 Architecture and Development

The server agent is responsible for the communication with the client side by providing forms based on HTML, JSP (Java Server Pages) and AJAX (Asynchronous JavaScript And XML) technologies to show

[3] http://decsai.ugr.es/ jgomez/thesis/

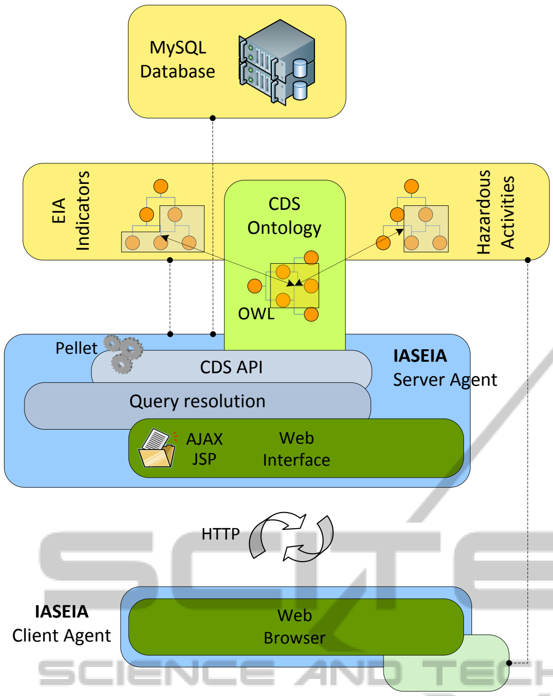

Figure 1: Architecture of the EIA support application.

and retrieve information. This module has also control over the query resolution and the CDS API modules (the knowledge-data layer), whose main task is the extraction of the relevant knowledge for the scenario considered by a specific context.

The knowledge-data layer consists of the context ontology model, the domain ontology model, the CDS ontology model, and a MySQL database. As it is explained in Sect. 3, the three models are needed for the query resolution and extraction of the relevant domain and they are allocated into an ontology server. The database is used to store the collected information during the environmental assessment.

4.2 Use

The functioning of the IASEIA system is the following. Let us suppose an auditor that needs to perform an environmental assessment for a company, installation, or activity. The auditor can move to the place to be evaluated bringing a smartphone or a similar device with navigation capabilities. The auditor inspects the place and accesses to the query form in the web application (see figure 2). At this point, the auditor can choose the set of actions best suited to the real scenario from the structured list retrieved of the context knowledge base. Once the current scenario is selected, the auditor sends back the form to the IASEIA application.

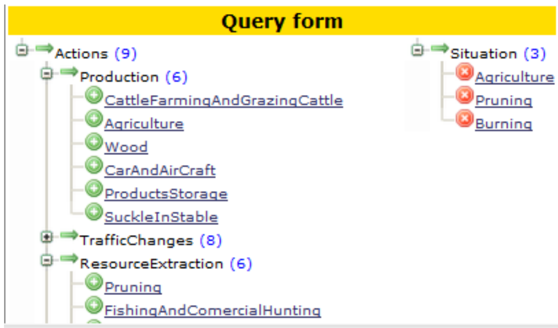

Figure 2: Query form for IASEIA.

The server agent receives the description of the impacting actions that will be performed and uses them as the input for the CDS API implementation of the CDS reasoning algorithm. The algorithm finds out the significant domain for the context description –i.e., the relevant indicators–, which is used to fill the form that is sent to the auditor (see figure 3).

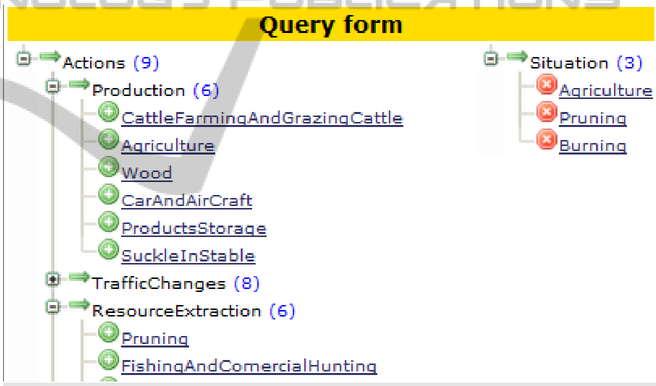

Figure 3: Data form for IASEIA.

The indicators form offers a list of indicators and a corresponding text field for each of them. The auditor must fill the form with the measured values, besides some additional data: the date of the assessment, the company, etc. Finally, the collected data are sent to the server, which acknowledges the values by displaying them after checking that the transaction is right.

5 CONCLUSIONS

This paper presents an ontology-based system to assist environment data acquisition for environmental impact assessment, a problem affected by information overload. The IASEIA application facilitates the selection of the most appropriate environmental indicators to be evaluated for a given set of impacting actions.

The knowledge base of IASEIA has been developed by relying on the CDS pattern, an ontology design pattern to create ontologies that allows the characterization of the significant domain information of a given context. The CDS pattern promotes modularity and reusing of the knowledge models. Thus, it is possible to enhance the models by adding or creating more specific ontologies covering more detailed aspects of the EIA process. The context and the domain ontologies can be easily extended with additional knowledge to describe additional actions and indicators. Building a comprehensive actions ontology is a difficult task, and therefore it may be necessary to incorporate new terms to describe actions that were not predicted in the development of the context ontology. Similarly, indicators may change if different assessment methodologies are used.

Actually, our ongoing and future work is focused on the enhancement of the knowledge models under the supervision of environmental experts. The development of more accurate models will serve as a basis for the future real use of the system, both in indoors and outdoors scenarios.

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