A VISION FOR A FRAMEWORK TO SUPPORT MANAGEMENT OF AND LEARNING FROM CONSTRUCTION PROBLEMS

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ABSTRACT

Construction projects are information-intensive. The availability of integrated project data and the recording of such data throughout the construction process are essential not only for project monitoring, but also to build a repository of historical project information that can be used to improve future project performance. This paper describes ongoing research and proposes a knowledge-based framework that uses ontological engineering to help retrieve and disseminate construction engineers' tacit knowledge in managing on-site construction problems. A Problem/Action (P/A) model is presented to describe the relationships between relevant concepts describing a P/A pair. The ontology-driven search mechanisms implemented will enable users to query for P/A pairs based on the related "concepts" rather than on mere "keywords" used to describe the problems. The authors expect that the envisioned framework will enable standardized storage and retrieval of construction problems/actions knowledge and apply an automated, semantic reasoning process to manage reported knowledge. This would allow construction engineers to better share and use corporate knowledge when searching for appropriate actions to remedy on-site construction problems. The shared knowledge is also expected to help better predict the impacts of remediation actions in a project life cycle, positively affecting their cost and schedule ramifications.

KEYWORDS

Construction problems, Reasoning mechanisms, Ontologies, Learning, Knowledge Management, Construction Industry

1. INTRODUCTION

Knowledge management systems have been subject of considerable research in civil engineering in recent years. Knowledge management involves creating, capturing, storing, retrieving, and disseminating knowledge. Throughout the construction of any facility, knowledge is gained and lessons are learned, but little of this hard-earned experience is electronically captured in a manner that allows knowledge to pass from project to project and from person to person (Tserng and Lin 2004). Many organizations are now engaged in knowledge management efforts to leverage knowledge both within their organization and externally for the benefit of their employees and customers (Lima et al. 2005, El-Diraby and Zhang 2006).

A knowledge-based system aims to leverage the plethora of knowledge by making it retrievable and sharable among practitioners to help reduce the time and cost associated with rework, waste, and on-site field problem management.

1.1 KNOWLEDGE-BASED SYSTEMS FOR CONSTRUCTION

Knowledge-based systems for construction management target many different construction areas, such as site planning, risk management, document sharing, project control, progress monitoring, and cost estimation. There have been studies of on-site construction problem processing and document and information sharing (e.g. Russell 1993, Russell and Fayek 1994, Kartam 1996, Wang et al. 2007, Zhu et al. 2007). Russell (1993) developed a computerized program to collect and process site information based on traditional superintendents' daily site reports. In addition, Russell identified a list of problem sources that can result in time, cost, quality, and safety problems at construction sites. Russell and Fayek (1994) developed a framework for automated interpretation of job records to identify problems in activities and suggest corrective actions. The actions were suggested based on activity attributes and problem types. For reasoning, the prototype utilized fuzzy logic combined with expert rules to describe the relationships among the activity attributes, corrective actions, and problem sources. Kartam (1996) presented an interactive knowledge-based system for constructability improvement, where construction lessons were analyzed and classified into the 16 divisions of the Master Format System based on the Construction Specification Institute (CSI). The system included alternative means to information access and multiple views of the knowledge base to improve on-site construction processes. El-Diraby and Zhang (2006) developed a web-based knowledge system to support the representation and utilization of corporate memory in the construction domain. The system used a taxonomy for building construction to retrieve semantically related construction reports and meeting agendas. Moreover, Wang et al. (2007) developed a knowledge-based fuzzy neural network to diagnose problems observed throughout the implementation of professional construction management in Taiwan. Zhu et al. (2007) demonstrated the usability of Industry Foundation Classes (IFCs) for constructing a metadata model for requests for information (RFI) that enhances the retrieval of RFI related information.

1.2 SEMANTIC SYSTEMS IN THE CONSTRUCTION INDUSTRY

Human knowledge can be efficiently presented through semantic systems that utilize ontologies to encapsulate and manage the representation of relevant knowledge (Lima et al. 2005). In computer science, ontologies are a technique used to represent and share knowledge about a domain by modeling the concepts in that domain and the relationships between those concepts (Gruber 1993). Specifically, ontologies provide a knowledge representation form using a system of concept hierarchies (taxonomies), associative relations (to link concepts across hierarchies), and axioms (El-Diraby et al. 2005). Thus, ontologies enable reasoning about semantics between domain concepts and can play a crucial role in representing knowledge in the construction industry (Lima et al. 2005, Rezgui 2006).

A variety of semantic resources ranging from domain dictionaries to specialized taxonomies have been developed in the construction industry. Among them are BS6100 (Glossary of Building and Civil Engineering terms produced by the British Standards Institution); bcXML (an XML vocabulary developed by the eConstruct IST project for the construction industry); IFC (Industry Foundation Classes developed by the International Alliance for Interoperability); OCCS (OmniClass Classification System for Construction Information) , BARBi (Norwegian Building and Construction Reference Data Library); and e-COGNOS (COnsistent knowledGe maNagement across prOjects and between enterpriSes in the construction domain) (Rezgui 2006, Wang and Boukamp 2007). Amongst these semantic resources, the e-COGNOS project was the first project to deploy a domain ontology for KM in the construction industry and has been tested in leading European construction organizations (Lima et al. 2005).

Practitioners and researchers have acknowledged limitations of the current approaches for managing information and knowledge related to and generated throughout construction projects (Russell 1993, Kartam 1996, Rezgui 2006). Despite the interest and the effort put into knowledge management (KM) by researchers and companies, many of the systems applied are dealing only with abstract documents including reports, manuals, and claims. Little research tackles the tacit knowledge and experience that exists in the heads of engineers and experts, which would have to be semantically formatted in models to allow this knowledge to be shared and disseminated among practitioners (Tserng and Lin 2004).

This paper describes the vision of the authors' ongoing research effort to develop a knowledge-based framework that uses ontological engineering to retrieve and facilitate the dissemination of construction engineers' experience in managing on-site construction problems. The framework will enable standardized reporting of construction problems/actions knowledge and apply an automated, semantic reasoning process to manage the reported knowledge. Problems/actions (P/A) relevant information will be incorporated in this framework together with related decision-making knowledge stored by the construction engineers.

2. OBJECTIVE

The objective of this ongoing research is to identify and understand the semantics amongst heterogeneous construction problems' relevant information as well as their complex interdependencies. This understanding will help in the development of ontologies and model-based adaptive mechanisms that can organize problem/action relevant information according to content and interdependencies. In other words, a semantic knowledge-oriented framework will be developed to allow more efficient representation of tacit knowledge related to construction problems. The Construction Problem Framework (or framework for short) will allow construction engineers to efficiently store, and update their construction problem information. In addition, search mechanisms will allow them to semantically refine their search for remediation actions. The standardized management of semantically rich construction problem/action information will support construction managers' efforts in searching and finding specific documents of interest and learning from information about past problems. Thus, the framework is expected to improve problem management at construction sites. To better elaborate the framework's target functionality, an illustrative scenario is presented in the following section.

3. ILLUSTRATED SCENARIO

The following scenario description aims to help better visualize the envisioned framework and its potential benefits to construction professionals.

Situation: Bill, a construction engineer, is sitting in his office and thinking of a solution to a construction problem: The concrete samples taken from "Column C12-11 in Building C" do not achieve the required strength. His remediation action will certainly affect the construction process by increasing cost and required time. He has the Construction Problem Framework installed on his laptop.

According to company policy, Bill has to report any construction problem using the Construction Problem Framework, which then stores the collected information in a shared database on the company's intranet. He now uses the framework to create a record of his concrete strength problem and to search for similar problems that have been reported by other engineers in the company to get ideas about how to solve the problem. The Construction Problem Framework provides a number of ontologies that contain semantic descriptions of *products*, *processes*, *resources*, and *unplanned situations* and their relationships. Since the framework requires a specific structure for describing the core data of a problem, Bill can drag-and-drop concepts from the ontologies to describe the problem. For example, 'column' and 'slab' are classified as building products in the *Product* ontology, and 'concrete' is classified as a material in the *Resource* ontology. This not only allows Bill to perform ontology-based searches when recording a new problem but also supports building a database containing the corporate memory of construction problems related to semantically defined concepts. Bill can also add comments and attach sketches and photos in order to fully describe the problem. Now, Bill chooses the concepts 'column', 'cast-in-place', and 'concrete' to describe his problem. The first step is finished.

The search tool offered by the Construction Problem Framework allows Bill to navigate the company's P/A database searching for problems similar to the current problem. Since the system's ontologies specify that the concepts 'formwork', 'rebar', and 'curing' are related to the concepts 'cast-in-place' and 'concrete', the system identifies problem/action (P/A) records that are related to all of these concepts. After retrieving the records, the system allows Bill to change the automatically identified search parameters. Bill indicates that the concepts 'formwork' and 'rebar' are irrelevant to his problem, but he's glad that the system identified the related concept curing for him. Finally, his search results in the identification of exactly three P/A records. He reviews each of these records and finds out that one of the recorded actions can possibly be applied to his problem. To get further details about this potential solution, he contacts Mrs. Miller who created the report and works in the East Coast Division of his company. Now Bill has identified a plan to solve his problem using a slightly modified version of Mrs. Miller's approach. The second step is finished.

Bill considers using Carbon Fibers to support the column instead of demolishing and reconstructing, and calculates the additional cost and time required as relative consequences to this action and updates his problem/action record in the system. After the successful implementation of this solution, Bill updates the problem record a final time to add a solution evaluation, which contains information about the effects of the solution on the project, such as the related cost increase and schedule delay, so other engineers can draw upon his knowledge in the future. The third and final step is finished (see Fig. 1).

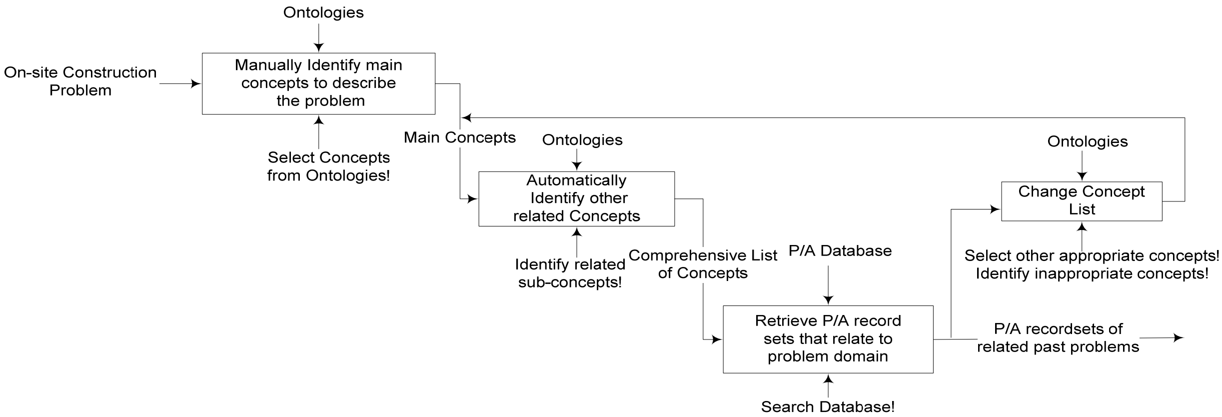

Figure.1: IDEF0 depicting the Construction Problem/Action Information Retrieval Process

The framework and the framework requirements are identified and described in the following sections.

4. THE FRAMEWORK STRUCTURE

The authors envision the framework to consist of two layers, as illustrated in Fig. 2:

- Service layer: the service layer offers the user interface (UI) functionalities for the system. A set of functionalities is provided as separate services which respond to user requests and forwards them to the knowledge task manager in the system layer. The service layer will allow the user to access different functionalities to store the new construction problem related information, update existing information, search for specific information related to problems, and to maintain and update the related ontologies.
  Since the functionalities are provided as services, they can be easily integrated in a company's existing knowledge management system.
- System layer: The knowledge management system layer supports all the services provided by the system. It processes user requests coming from the service layer. The system layer consists of the following components, which are described in greater detail in the following sections:
  1. Problem/Action Model
  2. Problems/Actions Database
  3. Ontologies
  4. Knowledge Task Manager

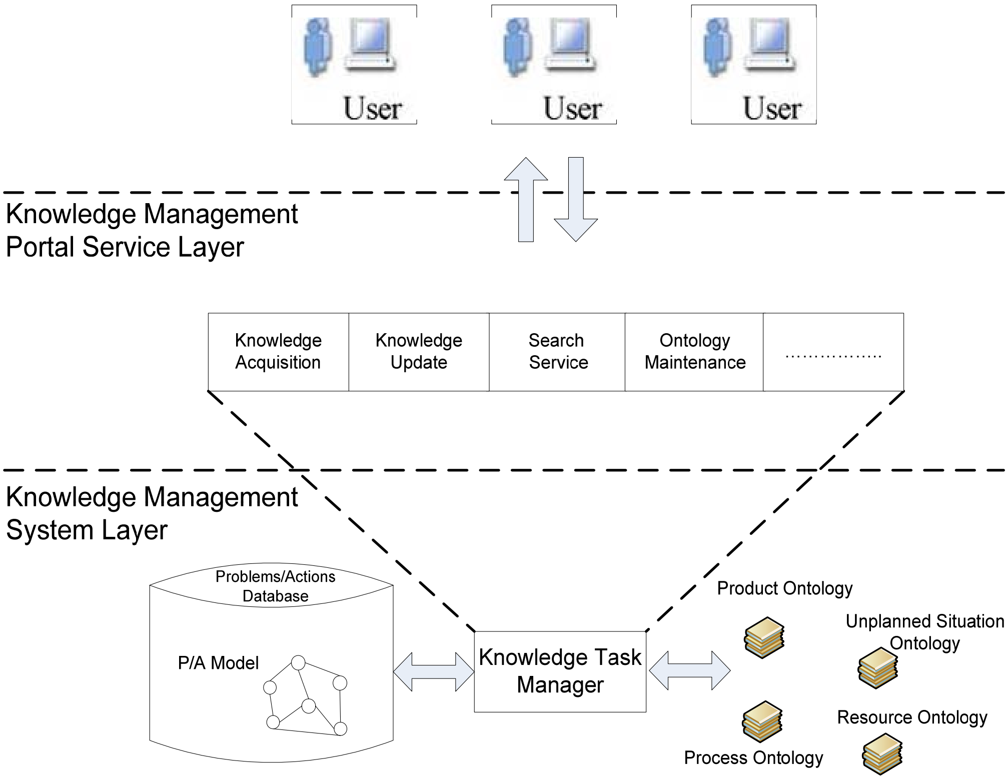

Figure 2: The Construction Problem Framework Main Platform

4.1 PROBLEM/ACTION MODEL

Several researchers have defined construction problems as unplanned situations leading to detrimental effects on construction project aspects (e.g. Mitropoulos and Howell 2001, Levy 2007). A common similarity between construction projects is that each problem encountered is paired with a set of corrective actions taken to overcome the problem. Russell and Fayek 1994 claimed that construction activities can be described in a set of attributes and be incorporated in a model together with problem sources and corrective actions.

Building on these ideas, the authors of this paper developed an ontological model to describe the structure of construction problems with respect to the relationships between relevant concepts that should be stored in the Problem/Action model to describe Problem/Action pairs. The Problem/Action ontology can be summarized as follows: Construction problem knowledge is encapsulated in a model, where a set of *Construction Problems* reported by a set of *Actors* result from a set of *Unplanned Situations* in a *Project* and refer to a set of *Processes*, which produce a set of *Products* that utilize a certain combination of *Resources*. *Construction Problems* result in *Problem Consequences*, which are identified according to a set of *Technical Topics* and are solved by a set of *Problem Resolving Actions*.

The Problem/Action Model developed out of this Problem/Action ontology combines only 10 concepts. This allows the model to be generic enough to be applicable to all on-site construction problems in general, while being specific enough to support the envisioned ontological engineering approaches described in the succeeding sections, which will support more efficient knowledge storage, retrieval and dissemination. A UML diagram of the Problem/Action Model is shown in Fig. 3.

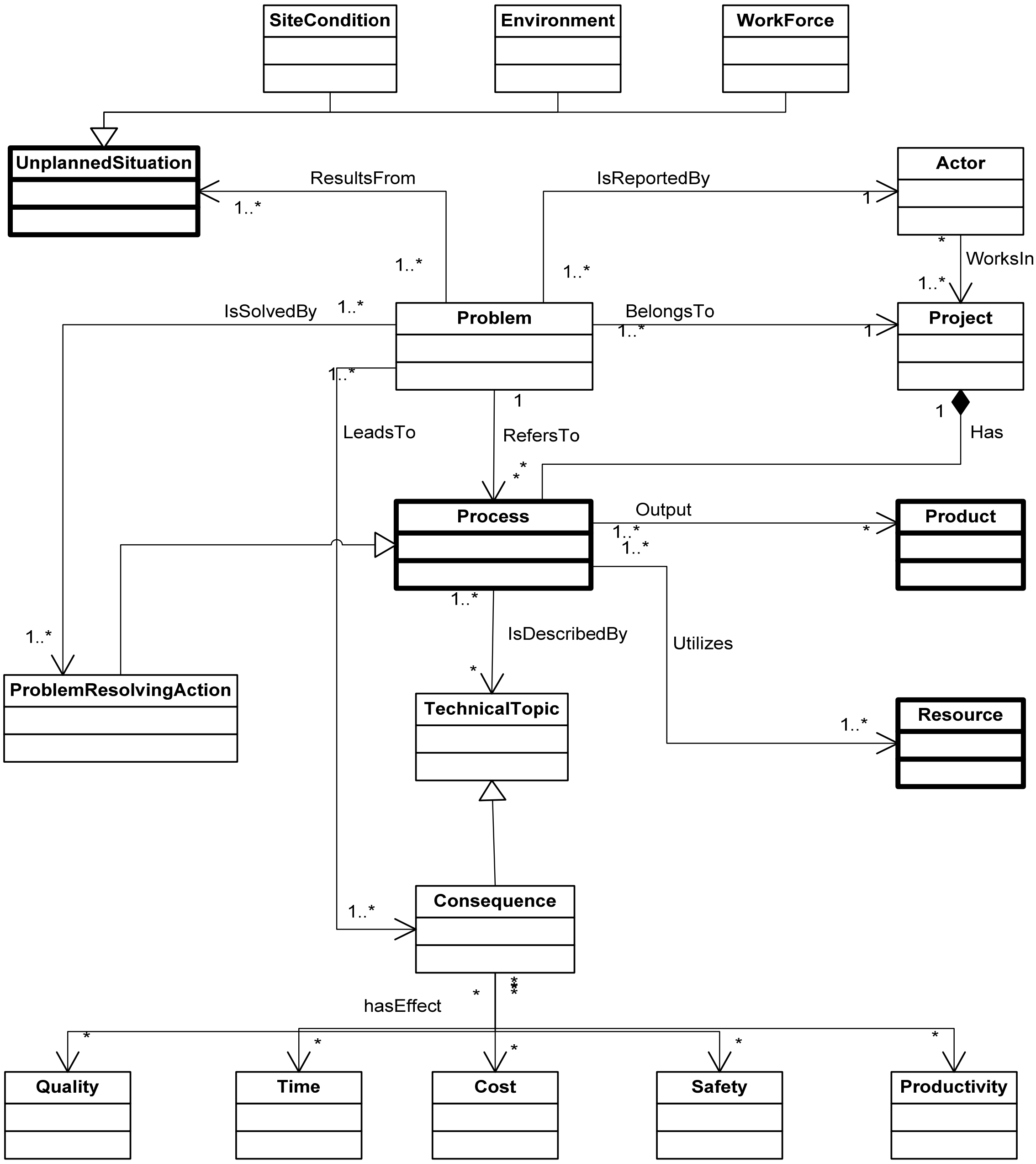

Figure 3: UML diagram of the Problem/Action Model

It should be noted that this Problem/Action model contains six concepts predefined in the e-COGNOS domain ontology, namely Project (PJ), Process (PR), Product (PD), Actor(AC), Resource (RE), and Technical Topics (TT). This allows for integration of the Problem/Action model with other models developed in the context of e-COGNOS.

4.2 ONTOLOGIES

Some of the above mentioned concepts used to describe a Problem/Action pair should be extended and represented through a number of ontologies, from which specific sub-concepts can be chosen that will be linked to the P/A pair in the P/A database. The authors propose to use an initial set of four ontologies: *Product* ontology, *Process* ontology, *Resource* ontology, and *Unplanned Situation* ontology. Among the specific sub-concepts represented in each of these ontologies, the user will only have to select suitable concepts that describe his/her problem. Upon linking these ontologies to our P/A model, the user will gain access to the concept scheme, which provides access to related concepts as well. On the one hand, the relationships between the concepts can help guide the user in choosing the appropriate terms for the problem description. On the other hand, this setup will support the ontology-driven search mechanisms in returning more significant results relevant to the search parameters specified by the user when searching for similar problems in the database.

Various taxonomies have been developed that have the potential to serve as a starting point for developing the required sub-concept ontologies. Among these taxonomies are BS6100, bcXML, ISO 12006-2, IFC, OmniClass, and BCTaxo (El-Diraby and Zhang 2005, Rezgui 2006). The *Product* ontology, *Process* ontology, and *Resource* ontology are predefined in BCTaxo and can be further extended in our framework (El-Diraby and Zhang 2005). The forth ontology representing the *Unplanned Situation* builds on previous research performed by Russell (1993) and Russell and Fayek (1994) to identify problem sources. The later research identified various problem sources and grouped them in 10 categories. A partial list of Product, Resource, Process, and Unplanned Situation taxonomies is represented in Fig. 4.

The ontologies will be stored in OWL (Web Ontology Language) files in the system and will be kept separated from the P/A database. This will allow the administrator to modify and update the ontologies with new concepts without altering the P/A database. A full description of the database functionalities is given in the following section.

4.3 PROBLEM/ACTION DATABASE

The P/A database is a relational database that holds the problem/action pair information. The information in the P/A database will be structured according to the P/A model described earlier. Documents, such as sketches, comments, and pictures needed to describe a construction problem and action will be embedded in the P/A database through links to the files. Similar to MIA's approach (MIA 1998), the data stored in the database will be classified into 2 groups: Administrative data and Problems/Actions data. The database stores administrative data in an *authentication* table that stores user-names and passwords to provide different levels of access and keeps track of different users of the system.

The P/A information for each problem is stored separately in the database. The *problem* and *action* related tables will allow the user to store links to any documents, photos, and sketches related to the problem or the action. Each class of the P/A model is represented in tables. The user will be able to identify the *Product*, *Resource*, *Process*, and *Unplanned Situation* describing concepts using the ontologies. The identified concepts chosen from the ontologies will be stored in appropriate tables in the database.

Product
- Software
- Basic Products
- Management Product
- ConstructionComplex
- Civil Product
- Industrial Product
- Building Product
- Column
- Slab
- Foundations
- Construction Aid
....
Resource
- Material
- Concrete
- Aggregate
- Cement
- Sand
- Equipment
- Heavy Machinery
- Drilling Equipments
- Labor
- Software
....
Process
- Design Process
- Operation Process
- Construction Process
- Conc. Construction Process
- Cast in Place Conc.
- Earth Removal Process
- Maintenance Process
- Electronic Process
....

Unplanned Situation
- Site Condition
- Cleanliness
- Site Unavailability
- Storage Space
- Ground Condition
- Consultant/Architect
- Payment Delays
- Changes
- Site permission
- Drawings
- Errors
- Insufficient Information
....
- Workforce
- Lowskill Level
- Unsafe Practices
- Work
- Subcontractors Errors
- Rework
- Supplies/Equipment
- Material Inspection
- Equipment Breakdown
....

Figure 4: A partial list of Product, Resource, Process, and Unplanned Situation taxonomies

The database server is centralized on the organization's main system. A firewall can be built to protect the system database against intrusion. Project participants may have access to all or some of the problem/action information through the organization's Intranet, as determined by their levels of access authorization (Tserng and Lin 2004). Any information about a construction problem can be stored in and obtained from the system database only through a secure interface that requires each user to log in.

4.3 KNOWLEDGE TASK MANAGER

The knowledge task manager is responsible for processing the service request from the service layer. When the user starts to provide new information to the system, the task manager links the ontologies to the application view to assist the user in exactly defining the product, resource, process, and the unplanned situation information relevant to the problem. Subsequently, the task manager stores the new problem information in the P/A database.

The task manager controls the search process by again linking the ontologies to the application view so the user can define the search boundaries, keywords, and relationships. Once the search parameters are defined and provided to the task manager, it creates a link to the P/A database and searches for existing problem/action records using ontological reasoning mechanisms. Those reasoning mechanisms are described in the following section.

5. REASONING MECHANISM

When the system is implemented at an organization's intranet, users will be able to query for problems/actions based on the related "concepts", rather than on mere "keywords" used to describe the problems. Similarly, when a user saves problem/action information to the corporate database, it will be classified according to the related concepts, which are defined through the ontologies in the system. The ontology-driven search mechanisms return more significant results than those generated by a traditional keyword search mechanism.

To define search parameters, a user will be able to select concepts from the ontologies in the system. Each of the concepts is linked to other related concepts through ontological relationships. These ontological relationships allow the reasoning mechanism to determine what other problem records are filed under other concepts that are related to the concepts chosen by the user.

For example, let us assume that the construction engineer is indexing a construction problem similar to the one described in the illustrative scenario. A number of keywords come to the engineer's mind for describing the problem: Column, Concrete, Strength, Cast-in-place. The construction engineer will then select the concepts related to these keywords. Based on this methodology, the concept Column will be retrieved from the Product Ontology, the concept Concrete will be retrieved from the Resource Ontology, and the concept Cast-in-place will be retrieved from the Process Ontology (see Fig. 4).

The main problem of information search is that the majority of information search mechanisms are primarily based on keywords; and "words" alone don't have meaning or semantics (Lanin and Lyadova 2007). When the construction engineer searches for problems similar to a 'cast-in-place concrete column' problem through a traditional keyword-based search, he/she might end up finding unrelated problems, e.g. "pre-cast Concrete" problems if "Concrete" was a keyword used for the search. If the keyword combination "cast-in-place concrete" is used, problems related to cast-in-place concrete will be retrieved, but "concrete pouring" problems that do not contain the keyword "cast-in-place concrete" in their description, will not be retrieved, even though they are related.

The envisioned approach uses an ontology-driven search mechanism that uses knowledge about the relationships between concepts. For example, when the user selects the process concept "Cast-in-Place" and the resource concept "Concrete", the system will be able to determine that problems related to "cast-in-place concrete" should be retrieved, while problems related to "precast concrete" should be ignored. Additionally, the system can highlight other problems related to cast-in-place concrete, such as formwork problems, rebar problems, curing problems, etc. Through re-adjusting the search parameters, e.g. by selecting the resource concept "formwork" as inapplicable, the user can improve the search results.

Also, the user can generalize his/her query for problems by selecting more general concepts, e.g. "Concrete" as a Resource, "Building Product" as a Product, and/or "Construction Process" as a Process. The system then will return records of problems that encompass not only concrete columns but also slabs and foundations (see Figure 2). In addition, the construction engineer will have access to the personnel (actor) who reports the problem so he/she can contact him/her personally to get feedback on a specific technical issue.

6. SUMMARY AND CONCLUSION

This paper presented an overview of a system currently being developed and researched by the authors. The system is a knowledge-based framework that shall help retrieve and disseminate construction engineers' experience of managing on-site construction problems. The framework is envisioned to enable standardized reporting of explicit and tacit knowledge about construction problems/actions and will apply an automated, semantic reasoning process to manage the reported knowledge. The framework can be integrated with different construction semantic resources such as e-COGNOS and BCTaxo. A Problem/Action (P/A) ontological model has been presented to describe the relationships between relevant concepts describing a P/A pair. The Problem/Action model developed combines ten concepts. A set of four ontologies - *Product* ontology, *Process* ontology, *Resource* ontology, and *Unplanned Situation* ontology - will be used to help conceptualize four of the concepts represented through the P/A model.

The framework is envisioned to be implemented at an organization's intranet. Therefore, users will be able to query for problems/actions records based on the related "concepts" rather than on mere "keywords" used to describe the problems. Ontology-driven search mechanisms are implemented to respond more efficiently to construction engineers' queries, thus returning more significant results than those generated by a traditional keyword search mechanism. The standardized management of semantically rich construction problem/action information will support construction managers' efforts in searching and finding specific documents of interest and learning from information about past problems. Thus, the framework is expected to improve problem management at construction sites.

Research related to the ontological reasoning mechanisms and the development of related concept ontologies is ongoing. It has to be identified how concepts in the ontologies should be linked semantically to support the developed reasoning mechanism and how the ontologies can be kept manageable, so that companies can enhance their ontologies, e.g. if new problem types appear which should be described with new concepts. Additionally, it needs to be investigated whether other concept ontologies, aside from the Product-, Process-, Resource-, and Unplanned Situation-concept ontologies, would benefit this system.
Additionally, research should be conducted in linking our P/A model with integrated project models (IPMs) to allow leveraging the project information available in IPMs. This integration is expected to help study and manage the impacts of problems on a project and may potentially help reduce or even avoid problem propagation throughout the construction lifecycle.

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