ONTOLOGY-BASED OPTIMISATION OF KNOWLEDGE MANAGEMENT IN e-CONSTRUCTION

SUBMITTED: December 2004
REVISED: September 2005
PUBLISHED: November 2005 at http://www.itcon.org/2005/21/
EDITOR: Z. Turk

C. Lima, Dr.
Centre Scientifique et Technique du Bâtiment, Sophia Antipolis, France
email : celson.lima@cstb.fr

T. El- Diraby, Assistant Professor
Department of Civil Engineering, University of Toronto, Canada
email: tamer@ecf.utoronto.ca

J. Stephens, Project manager
Taylor Woodrow, Technology Centre, Bedfordshire, UK
email: jeff.stephens@uk.taylorwoodrow.com

SUMMARY: *The e-COGNOS platform presents the first comprehensive ontology-based portal for knowledge management in the construction domain. The main features of the platform are an ontology (to encapsulate human knowledge) and a set of web services to support the management of ontology (creation, updates), user management (profiling) and handling knowledge management requirements (indexing, documentation, retrieval and dissemination). Implementation of e-COGNOS platform (at leading European construction organizations) has proven the benefit of semantic systems as they provided adequate search and indexing capabilities, allowed for a systematic procedure for formally documenting and updating organizational knowledge (through the ontology) and enhanced the customization functions in a knowledge management systems (through user profiling). The development and implementation of the e-COGNOS platform has also shown that the managerial aspect of knowledge management (in terms of integrating knowledge in daily processes and the link between knowledge and organizational structure) is harder to attain.*

KEYWORDS: *ontology, knowledge management, eBusiness, semantic systems.*

1. INTRODUCTION

Effective knowledge management (KM) is an essential component for the sustainability of enterprises. The challenge of establishing and maintaining KM systems goes beyond the simple installation of e-business tools and software. KM systems have to represent (in a human-friendly manner) an encapsulation of organizational/domain knowledge. KM tools have to be intertwined into the day-to-day business process, be responsive to employee needs, and, ultimately, be an integral part of the organizational culture.

Within the realm of knowledge-economy, the construction industry faces two main challenges (CIRIA, 2000; Kazi et al, 1999)

- Technical challenges: Basically, how to develop, validate, update, implement and utilize knowledge encapsulation and representation systems along with web tools to manage organizational knowledge.
- Managerial (process and human) challenges: the revitalization of company structure and organizational culture to put the already developed KM systems into action. How to embed KM systems into work processes? How to integrate KM tools in the decision making cycle?

The second dimension is the main factor for the failure of many KM projects (Cooper, 1983; Davenport and Prusak, 1998).

Ontologies are gaining momentum as a tool for encapsulating knowledge (Fensel, 2003). Ontologies are defined as a shared conceptualization of the knowledge in a certain domain (Gruber, 1994). Based on the scope of the target domain, ontologies can be categorized into domain and application ontologies. Domain ontologies aim at modelling the fundamental concepts in a relatively large domain (for example, Biomedical, Manufacturing, etc.). In contrast, application ontologies focus on modelling sub-domains of a major domain. For example, and within the construction domain, one can think of the following application ontologies: cost, productivity, safety, etc.

Semantic systems utilize an ontology (or a set of ontologies) to encapsulate and manage the collection and representation of relevant knowledge, hence giving information a human-relevant meaning. Semantic description of project resources enhances construction collaboration through better understanding of document contents (supporting better understanding and extraction of knowledge) (Aziz et al., 2004). In addition, by introducing ontological reasoning, semantic techniques enable discovery of knowledge and information that was not part of the original use case or purpose of the ontology itself (Lassila and Adler, 2003).

To that end, several research efforts have capitalized on the wealth of construction classification systems and product models (namely IFC) to establish domain taxonomies/ontologies (Katanuschkov et al., 2002; Woestenenk et. al., 2002; Staub-French *et al.* 2003). Closely related is the work on conceptual modelling. Ekholm (1996) presented a pioneering conceptual/ontological model for construction works, where "Construction work parts are assembled and transformed construction products. The construction process uses the resources construction products, construction aids, and human effort (i.e. worker's labour and thought) and produces results that are both parts of construction works and other things and processes necessary for the production process. To analyse a part as work sections is a compositional view of the part. It includes aspects of the production activities and used resources including construction products and their constituent material". Work on conceptual modeling was extended to relevant sub domains particularly physical aspects of construction, such as structural analysis (Weise et al., 2003) or CAD layering (see for example, Bo-Christer et al., 1997). Other work on conceptual modeling focused on the process aspects of construction work, such as the decision making process (Cooper et al., 2005) and project definition (Whelton et al., 2002).

The e-COGNOS project (COnsistent knowledGe management across prOjects and between enterpriSes in the construction domain—IST-2000-28671) is the first to attempt to establish and deploy a domain ontology for knowledge management in the construction. The project incorporated the proposed ontology in a comprehensive KM system tailored to the construction industry. Finally, one of the most important aspects of the project was the actual deployment and testing of the KM system in leading European construction organizations.

This paper presents the e-COGNOS platform along with the results of its implementation and some lessons learned. The paper provides a general overview of e-COGNOS project. Next, the use of e-COGNOS ontology in KM is discussed. The use of e-COGNOS Ontology Server (e-COSer) is also presented. The paper also presents the feedback by industry on the use of ontologies in KM. The lessons learned from e-COGNOS project are then summarized along with set of recommendations for future work.

2. SCOPE AND KM SCENARIOS

The main hypothesis of the e-COGNOS project is that semantic systems present a feasible and effective way to support integrated KM in construction organization due to the fact that such systems allow for better presentation of human knowledge and, through the ontology, provide for efficient means for encapsulating and updating corporate knowledge. i.e., the main advantage of an ontology-based system is that ontologies can be built to encapsulate human knowledge in a machine-readable manner. Being object-oriented, the structure of an ontology itself provides for the development of additional ontologies (or versions of the original ontologies) in a flexible and interoperable manner. These two features: the human aspect and the maintainability of ontologies is what have made them integral part of other industries advanced KM systems.

Along with encapsulating knowledge in an ontology, this research project adopted web services as the main tool for building knowledge services. Web services are seen by many experts as the future of organisational interoperation via the Internet and are receiving strong support from both vendors and users. Therefore, the e-COGNOS portal utilized a set of Web-services related technologies, such as: Simple Object Access Protocol (SOAP), Universal Discovery Description and Integration (UDDI), Web Services Description Language (WSDL), and XML. The e-COGNOS KM platform was developed as a set of ontology-enabled web services that perform seven man activities: acquisition, cleansing/ transformation, indexing, updating, refreshing, searching/discovering, and sharing/ dissemination.

The objective of this research project was to work with industry to develop an ontology-based web services system for management of construction knowledge. Specifically, to support the following KM scenarios:

Scenario I: Capturing and reusing knowledge:

a) Knowledge documentation and storage: supporting a consistent approach for documenting lessons learned in ontology-based system that allows semantic retrieval of documents.

b) Knowledge extraction: knowledge extraction is an important functionality in KM. The prime need in this regard is the extraction of content and metadata from existing documents in different formats.

c) Knowledge classification: knowledge classification is a highly desirable functionality and one having a high priority. Existing tools only allow for the categorisation of knowledge. It is more important to support knowledge item clustering (finding similarities between knowledge items).

d) Search for knowledge items: the search, discovery, and ranking of knowledge items are issues of high priority with respect to both the manner in which these are done and in terms of the different types of knowledge items considered (full text search; searches on the basis; and discovery of experts and communities).

Scenario II: Management of formal organizational knowledge

a) Build/update/manage ontologies: ontologies embody corporate knowledge. There is a need to allow system users to update and amend organizational ontologies.

b) Integrate/import other systems: importing and integrating other classification/data exchange standards in the ontology is important to allow for better interoperability

c) Information security: providing proper access to users based on their needs and security clearance.

Scenario III: Integrating KM into organizational processes:

a) Knowledge Sharing and Assessment: knowledge sharing and assessment includes the publication (and dissemination) of valuable documents. It also includes discussion forums.

b) Knowledge Dissemination: this includes company news and specialised knowledge.

c) Creation and Synthesis of New Solutions: the creation of and synthesis of new solutions on the basis of existing ones.

d) Knowledge Maintenance: crawling of dedicated knowledge sources, keeping an eye on their changes, and the automatic notification of change to impacted knowledge items.

e) User Profiling: personalised user interfaces and shared virtual workspaces, and private configurable workspaces.

Technically, the e-COGNOS platform is composed of three main elements: the e-COGNOS ontology (housing a formal representation of domain knowledge), Ontology Server (e-COSer), which is used to manage the ontology, and the e-Construction Knowledge Management Interface (e-CKMI), which provides the main KM services. The ontology represents the abstract conceptual model for construction knowledge, encapsulating main concepts, their relationships and their constraints (axioms). The e-COSer is a server application responsible for managing the ontology (update, browsing, indexing, access rights). It is mainly dedicated to support Scenario II and provides support for some elements of Scenario I. The e-CKMI is the main KM service in the e-COGNOS platform. It offers a full range of KM tools (documentation, search, sharing, dissemination, collaborative creation of documents, etc.). e-CKMI is mainly dedicated to support Scenario I and III.

The e-COGNOS approach classifies construction knowledge into three main groups: *Domain knowledge* (administrative information, standards, technical rules, product databases, etc.), *Corporate knowledge* (the intellectual capital of a company), and the *Project knowledge* (the knowledge that each company has about the project). Orthogonal to these groups, a fourth group is also considered: *User knowledge*, which represents the knowledge (both tacit and explicit) possessed by the human actors. Within this context, a *Knowledge Item* (**KI**) is a unit of knowledge, such as *documents*, *images*, *CAD drawings*, *roles*, *knowledge classifications*, and *communities of interest*. Each KI has a knowledge representation (KR) within the corporate KM system, which is a semantic model (set of interrelated ontological concepts) that represents the knowledge within the KI (i.e., ontology-based model of the metadata of the KI).

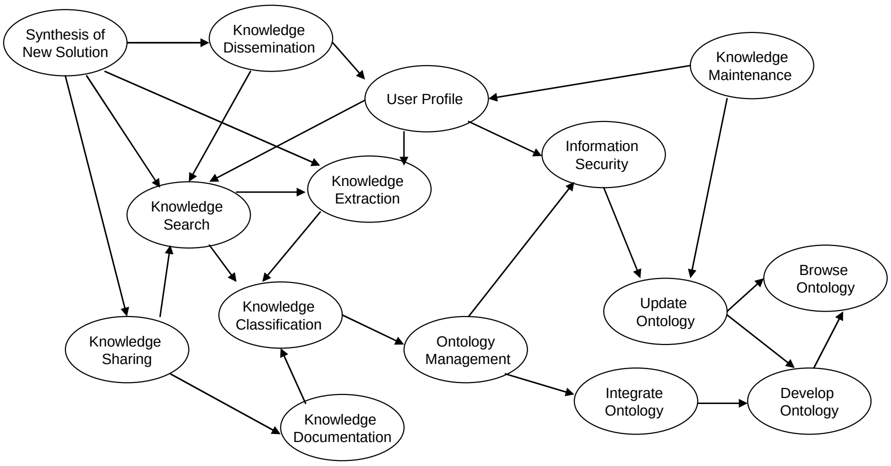

FIG. 1: Use Case Diagram

3. METHODOLOGY

Keen on assuring effective deployment on the organizational/human dimension, the e-COGNOS approach was designed to encompass the following features (based on benchmarking other industries):

- *Iterative development methodology*: the project adopted a cyclical approach that encompasses seven phases to guide the development of IT tools. This includes: project preparation, understanding and modelling core business processes, case study definition and description, measuring KM effectiveness, specifying the KM solution and building the KM strategy, implementing the KM solution, deploying and testing the KM solution / strategy, and evaluating the KM solution / strategy;
- *Process-based services specification*: clear identification of IT tools performance requirement and exact specifications as the result of examining and adapting the end user process models;
- *Flexible conceptual architecture*: the main functionalities of e-CKMI were identified to capture (in an object-oriented fashion) an expanding system for high-level components and requirements; and
- *Interoperable technical architecture*: encapsulates the components and functionalities presented in the conceptual architecture, referencing the technologies selected as appropriate for use in e-COGNOS.

End users Requirements: Early on, the e-COGNOS end users identified specific "knowledge intensive" business processes that were used to help in the discovery of functional, architectural, and technical requirements. The *functional* requirements included: human-centred, appealing, adaptive, configurable, and open KM systems. The *architectural* requirements (revealed after analysis of the end users business cases) are: web-centred environment, ontology-based, push mechanisms, autonomous processes, and knowledge layer interdependence. The most relevant *technical* requirements considered are: interoperability, integration, flexibility, scalability, sustainability, heterogeneous inter-related knowledge sources, and large knowledge sources.

Finally, a set of metrics were defined in order to evaluate the real impacts of e-COGNOS tools upon application within each organisation. Each industrial end-user customized these metrics, depending on their own business objectives. e-COGNOS tools were assessed against these metrics during field trials.

Ontology Development: The e-COGNOS ontology was built with the aim of supporting consistent/ extendable representation of construction knowledge. In addition to adhering and using best practice in the technical aspects of ontology development, the e-COGNOS team utilized the following guidelines (based on benchmarking other research project in construction and other industries) to properly address the managerial aspects of ontology and its integration with the overall business objectives of user organizations:

- Ontology should reuse or incorporate existing industry standards (e.g., IFC model, BS6100 and UniClass) as end users are already familiar with such standards;
- The ontology should be flexible and wide enough to accommodate the different business scenarios presented by the e-COGNOS end users. Nonetheless, the ontology was not meant to cover each and every concept in the construction industry. It is not feasible to produce a comprehensive list of all concepts and their relationships due to the limited time frame of e-COGNOS, the lack of sufficient precedence in the use of ontology in construction, and the diversity and relatively wide spectrum of the construction industry;
- The ontology should be user friendly, i.e., easy to browse and understand. It should be developed incrementally in close liaison with end users;

FIG. 2 shows the methodology adopted for the ontology development, which comprises the following phases: (**1**) literature review; (**2**) selection of basic terms, evaluation of end users' documents, review of existing taxonomies/classification systems; and (**3**) definition of major areas in the ontology, building the e-COGNOS taxonomy and enriching it with equivalent terms, creating the major relations among the concepts, and defining the minor relations. Please note that the 2nd and 3rd phases were performed together with the end users in an iterative process.

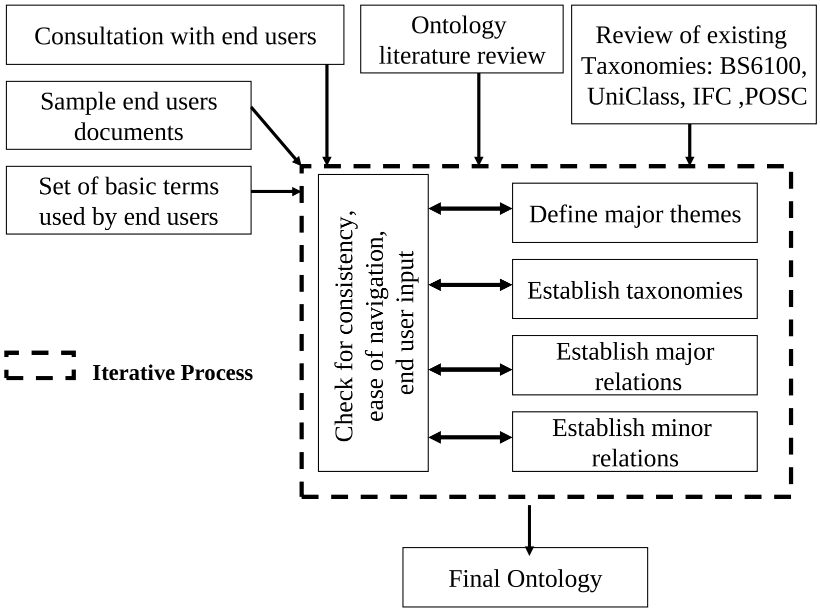

FIG. 2: Methodology for e-COGNOS ontology

<u>Building the Ontology</u>**:** As already mentioned, the e-COGNOS ontology was intended to be IFC compliant and to capitalise on previous taxonomies/classification systems. BS6100 and UniClass terms were used to enrich the ontology. The e-COGNOS approach in incorporating IFC resembles a superposition of two ontologies:

1. A "quasi" IFC ontology (called IFC.daml) was created using DAML. It preserves the relationships between major IFC concepts (an ifcObject is still a child of ifcRoot, an ifcProduct is still a child of ifcObject, and so on).

2. The e-COGNOS ontology was created to reflect, in part, the IFC structure. The root concepts of e-COGNOS ontology match those of IFC. Moreover, minor IFC concepts are included (e.g., ifcMaterialLayer and ifcSpace) in the e-COGNOS ontology.

3. The DAML+OIL tag "*equivalentTo"* is used to match e-COGNOS concepts to IFC.daml concepts (Root is "equivalent to" ifcRoot, Actor is *equivalent to* ifcActor, etc.). In other words, both classes (IfcConcept and Concept) are said to be equivalent to each other through the daml tag.

FIG. 3 illustrates the superposition concept. If someone searches the e-COGNOS ontology for "kitchen", it will be found under the concept of "Building space" and at the same time *ifcSpace*. When a user searches for the concept of "engineer" in e-COGNOS, it will be found under the concept of *Actor,* which is equivalent to *ifcActor*. Even though kitchen and engineer are not part of IFC, an IFC parser will be able to recognize them in the form of their upper level concepts (*ifcSpace* and *ifcActor*, in this example).

Ontology Validation: End users played the role of contributors as well as validators. The development of an ontology, by itself, is a gradual and evolving task. Initially, the end users provided a sample of documents that were analysed (through a semi-automatic process) by the ontology development team to identify a set of relevant keywords to support the development of a concept taxonomy. After some iteration, the first stable version of the e-COGNOS Ontology was made available to the end users, who were invited to evaluate it through a survey based on questionnaires, where the following questions were presented:

- How easy is to find concepts in the Ontology?
- How effective is the categorization of the concepts?
- Could there be more appropriate "domains" with which to categorize those concepts?
- How easy is it to categorise these concepts in the Ontology?
- How easy was it to navigate through the Ontology?
- How familiar are the terms used in the Ontology?
- How representative are the terms used (do you consider them to be major terms)?
- Overall, did the ontology cover the main domains of knowledge management in Construction?

Presentation and deployment: User organizations developed a set of dissemination actions, which aim to achieve 'buy-in' from employees. This included introducing the e-COGNOS solution and the expected benefits, workshops about the role of IT in KM, presentation of business cases (and the associated economic benefits), obtaining the users' contributions (in terms of problems, improvements, etc.), and identification of metrics to be used when evaluating the e-COGNOS solution.

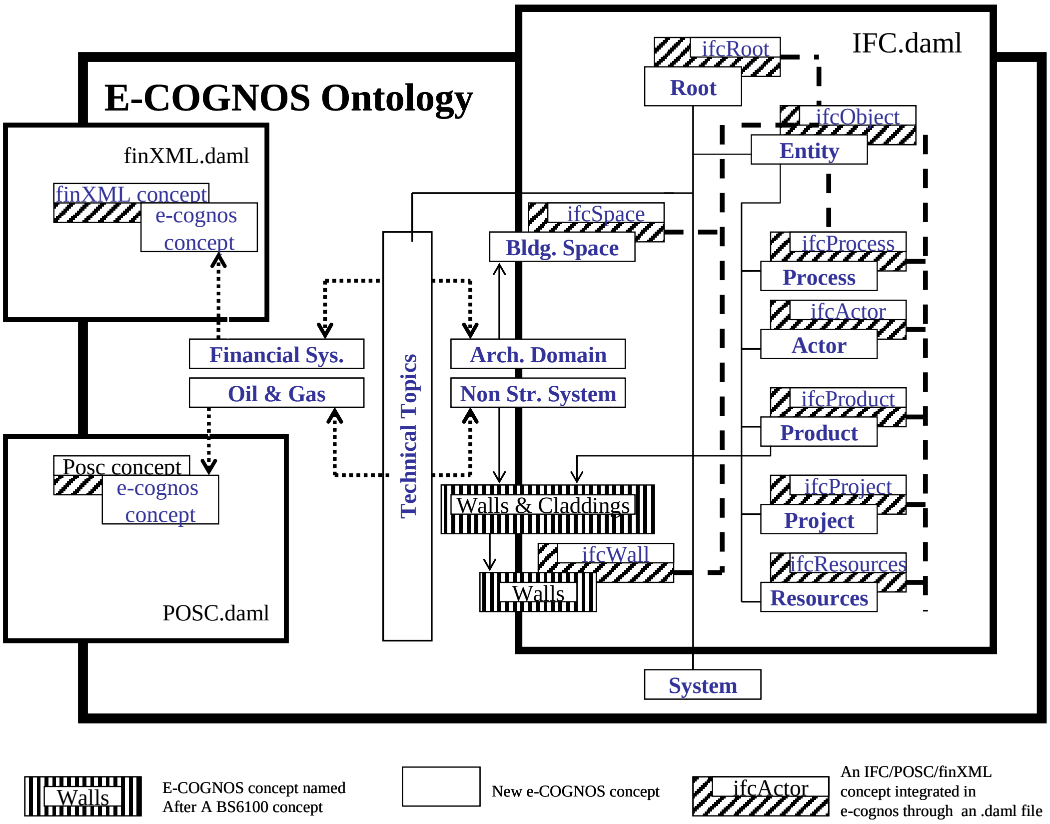

FIG. 3: The dynamic superposition approach

4. THE E-COGNOS ONTOLOGY

The e-COGNOS ontology was built based on benchmarking best practices in the construction and other industries. Two main models were very instrumental in this regard: the IFC model and the ISO 12006-3 model.

The primary target of the IFC Model is the interoperability among software applications within the building and construction market sector. The entities of the IFC model are grouped in layers where the kernel and core extension layers deal with general, abstract concepts whilst the shared elements and domain layers deal with specialized concepts that relate to real world ideas (IAI 2004). There are three primary forms of entity namely *objects*, *relationships* and *property* definitions. 'Objects' define the principal classifying ideas that exist in the building construction world. 'Property definitions' define additional data characteristics that can be applied to objects through external definition. 'Relationships' describe the connection that can exist between objects or between an object and a property definition.

The ISO 12006-3 (ISO 2002) is a Construction specific standard that defines a schema for a taxonomy model, which provides the ability to define concepts by means of properties, to group concepts, and to define relationships between concepts. *Objects*, *collections* and *relationships* are the basic entities of the model. The role that an object is intended to play can be designated through the model and this provides the capability to define the context within which the object is used. Objects are divided into *xtdSubject*, *xtdActivity*, *xtdActor*, *xtdUnit*, *xtdMeasureWithUnit* and *xtdProperty* entities. Objects may be related to formal classification systems through the provision of references (CEN/ISSS 2004).

The basic ontological model of the e-COGNOS ontology is as follows: *a group of* ***Actors*** *uses a set of* ***Resources*** *to produce a set of* ***Products*** *following certain* ***Processes*** *within a work environment (****Related Domains****) and according to certain conditions (****Technical Topics****).*

- The ontology is process-centered. Other domains define all relevant process attributes. For example, the ***Technical Topics*** domain defines the concepts of *productivity*, *quality standard and duration*.
- All entities (including Process) have three ontological dimensions: state, stage and situation. *State* concept captures the status of entity development: *dormant, executing, stopped, re-executing, completed*. *Stage* concept defines various development stages: *conceptualization, planning, implementation and utilization*. *Situation* concept refers to *planned entities* and *unplanned entities*.
- A ***Project*** is a collection of processes. It has two types: *Brown field projects* and *Green field projects*. It has a *project delivery system*, a *contract*, a *schedule*, a *budget, and resource requirements*. It also has a set of related aspects that include: *start time*, a *finish time*, *duration*, a *quality standard*, *productivity* level, a *life cycle* and a *life cycle cost*—all of which are defined in the ***Technical Topics*** domain.
- A ***Process*** has an *input* requirements that include: the completion of all proceeding processes, the availability of required *approvals*, the availability of required *knowledge items* (*documents*, *software*, etc.), the availability of required ***Resources*** (*materials*, *equipment*, *subcontractors*), the availability of required A***ctors***, and the availability of required *budget*.
- A ***Process*** has three major sub concepts: *Phase*, *Activity* and *Task*. It also has two major types: *engineering process* and *administrative process*.
- A ***Process*** has an output that include: update to a *product time-line*, an update to the *project schedule*, and update to the project *budget*, satisfaction/update to the *legal conditions*/*status* of ***Actors***, may result in creating some project *incidents* (an *accident*, *damage to an equipment*, etc.).
- A ***Product*** (also ***Actors***, ***Processes*** and ***Resources***) has *attributes*, *parameters* and *elements*, which are defined in ***Technical Topics***.

The e-COGNOS ontology is essentially composed of two taxonomies: a taxonomy of concepts and a taxonomy of relations. Those concepts and relations are grounded on the IFC entities, which are used to form the taxonomies highest levels. Concepts and Properties are specialisations of the *Object* class. In order to characterise a concept, the e-COGNOS meta-model defines the *Attribute* class, which is a specialisation of the *Relation* class. *Relation* is also specialised in *Signature* that enables the connection of two concepts.

5. THE e-COGNOS ONTOLOGY SERVER

The e-COSer is a stand-alone application. It is a Web-based application that plays two complementary roles: ontology management and the ontological support to the KM core services in e-CKMI (called the *LiaisOnto service)*.

Ontology Management Service (Scenario II): The first service in e-COSer supports the management of the ontology, performing tasks such as:

- Browse the concepts/relations: this allows navigation through the ontology, showing the description of both concepts and relations.
- Create new concept: this allows the addition of a new concept into the ontology.
- Create new relation: this allows the addition of a new relation into the ontology.
- Create new attribute: this allows the addition of a new attribute to a concept.
- Import bcXML taxonomy: this allows the importing of a bcXML taxonomy and its conversion into the DAML+OIL language.
- Remove concept: this allows removal of a concept from the ontology.
- Deprecate concept: this allows deprecation of a concept from the ontology. When a concept is deprecated, it is no longer accessible for the process of indexing new knowledge into e-CKMI but it is still accessible for searching of knowledge which has been indexed using the concept.
- Set the system settings: this allows the (de)activation of logging of system activity. It allows the tracing of the activity of the e-COSer and may help to solve problems which may appear. The log trace is also downloadable through the human interface.

The e-COSer offers three different levels of profile: *e-coser_user*, *e-coser_advanced*, and *e-coser_admin*. The *e-coser_user* profile allows the user to access the e-COSer with read-only rights. The *e-coser_advanced* profile allows the user to access the e-COSer with read/write access, and finally the *e-coser_admin* profile allows the user to access the application as the ontology manager, which confers a higher level in terms of control of the ontology. The ontology manager can modify some system settings.

Semantic KM Support Services (Scenario I): This service (called *LiaisOnto*) is used for the following use cases:

- Indexing: The service is deigned to accept a list of keywords, compare the keywords to ontological concepts, and produce a ranked list of ontological concepts that best matches that list of keywords. When a new KI is added to e-CKMI, the *LiaisOnto* is automatically invoked.
- Extraction: *LiaisOnto* uses an Extractor service to extract a representative set of keywords then use these keywords to assign a set of ontological concepts to each new KI. In essence, these concepts are metadata that are used to index each new KI. The *Extractor* service is responsible for extracting a relevant set of keywords from each new KI. For each keyword, it calculates a corresponding weight reflecting its relevance. The set of keyword-weight pairs is the semantic vector of the KI. This vector is then used to assign a hierarchy of relevant metadata to each KI. A KR is then built for the KI (including its metadata), which is then stored in the e-CKMI repository.
- Advanced Search: The *LiaisOnto* service is also invoked in advanced searches. If a user requests a search for a set of keywords (in a set of KR’s), *LiaisOnto* produces a matching ontological concept for these keywords, then matches the resulting concept to the metadata of target KR’s. This ontology-centred search is the essence of semantic systems, where search phrases and KR’s are matched through ontological concepts—in contrast to just looking for the same keywords in the target KR’s.

The e-COSer Technical Architecture: The e-COSer is composed of the following elements (FIG. 5): the Jena API, the e-COSer Layer, the Ontology manager, the LiaisOnto service, the Quarantine manager, the SOAP wrapper, and the e-COSer Human Interface.

The JENA Application Programming Interface provides the functionalities required to handle the DAML+OIL ontology. JENA is a Java-based API for manipulating RDF models. It includes a DAML API that provides support for loading DAML ontologies into Jena RDF models.

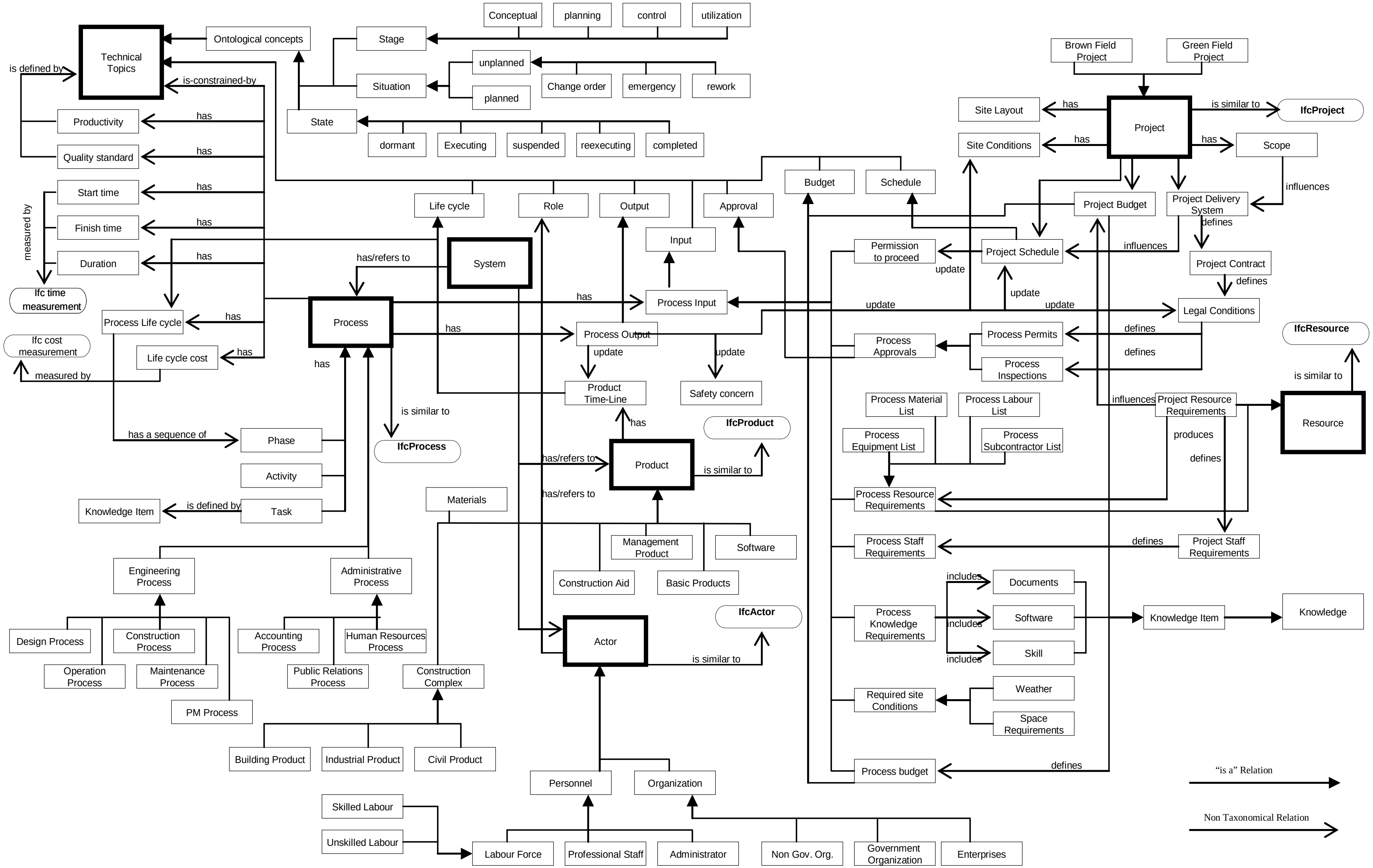

FIG. 4: Ontological Model for e-COGNOS Ontology

Within e-COSer, ontology is represented through a class model which contains concepts, relations, and attributes of the ontology. The e-COSer Layer guarantees the consistency between the DAML+OIL ontology loaded by the JENA API and the e-COSer class model, through wrapping the DAML+OIL java objects into e-COSer java objects defined in the class model. In other words, the e-COSer has its own model to represent ontology and it allows the e-COSer to be independent of the DAML+OIL language and the JENA API. The current version of e-COSer already deals with the OWL standard also.

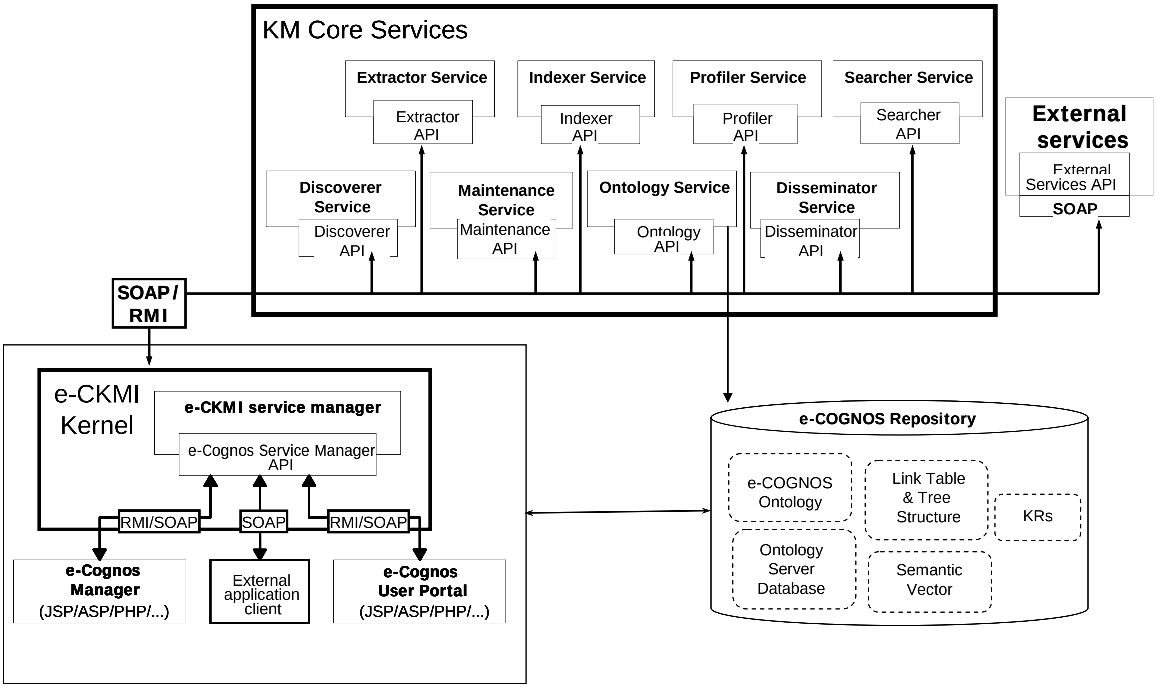

FIG. 5: e-COGNOS Functional Architecture

The Quarantine manager handles the suggestions (include / remove concepts and/or keywords) from the users. The suggested changes would be stored as "quarantined items" that should be evaluated and approved (or rejected) by the ontology manager. This mechanism intends to avoid undesired changes in the ontology structure.

The e-COSer SOAP wrapper is used to make the e-COSer accessible by any other web services (especially by the e-CKMI core services). Finally, the e-COSer Human Interface provides the functionalities to support the management of the e-COGNOS Ontology.

6. e-CONSTRUCTION KNOWLEDGE MANAGEMENT INFRASTRUCTURE (e-CKMI):

The e-CKMI is the third layer in e-COGNOS. It uses the ontology and the e-COSer to provide KM services to end users—mainly supporting scenario I and III (see Fig. 5). It is composed of a set of *KM Core Services* that have been structured into the seven main elements of KM life cycle: *acquisition*, *cleansing/transformation*, *indexing*, *updating*, *refreshing*, *searching/discovering*, and *sharing/dissemination*. One very important feature of the e-CKMI is its capability of being easily integrated with third party applications, through its SOAP-based API in a bi-directional way, i.e., from e-CKMI to other applications or the other way around. In the context of e-COGNOS, three end user web-based applications were integrated, allowing access to their internal knowledge. This knowledge could than be indexed and made available to the entire company via e-CKMI functionalities.

From the end users' perspective, the e-CKMI provides integrated and "transparent" semantic services. e-CKMI services are responsible for feeding the system with knowledge (textual documents, CAD drawings, web sites, etc.) that will be reused later on by themselves or other individuals.

Functional Architecture: One of the main requirements of user organizations explicitly pointed out the need of having the Web as the arena for e-CKMI to operate in. In e-COGNOS a Web service is defined as *software* *component that represents a business function/service and can be accessed by another application over public networks using generally available ubiquitous protocols and transports – e.g. SOAP over HTTP* (Pezzini 2001).

The architecture includes the following services (which support Scenario I and II): *e-COGNOS User Portal / Manager*, *e-CKMI API*, *e-CKMI Kernel*, *KM Services*, *e-CKMI Repository*, *e-COGNOS Wrapper*, and the *External Services*.

- The *e-COGNOS User Portal/Manager* represents the human interface to the e-CKMI and comprises two applications: the *Portal* and the *Manager*. The former is used by end users to capture, browse and search knowledge (stored and represented in the different knowledge layers). The latter, used by the e-CKMI administrator, supports the maintenance of the infrastructure, including the management of: (**i**) users and their respective access rights; (**ii**) security (privacy and visibility-related issues); (**iii**) data repositories and databases, (**iv**) ontology-related issues; and (**v**) KIs indexes and links.
- The *e-CKMI API* includes all the services provided by the "core" e-CKMI. It supports the requests coming from the client applications. From this perspective, both e-COGNOS Portal and Manager are considered client applications by the "core" e-CKMI.
- The *KM Services* have been structured into the seven categories of knowledge-related functionalities (corresponding to the aforementioned "classical" KM cycle). Two additional services were developed to support the management of ontology: *Ontology* and *LiasOnto* services.
- The *e-COGNOS Kernel* is the "backbone" of the architecture, where the KM services are registered and deregistered. It relies on the e-CKMI repository to store all of the information it needs to handle its tasks.
- The *e-COGNOS Wrapper* is intended to support interoperation with *External Services*. The *External Services* represent any specific services provided by a third party. Given that the e-CKMI is fundamentally a Web-oriented solution, the e-COGNOS Wrapper is likely to be converted into an integration mechanism based on XML, UDDI, WDSL, and SOAP. In this case, a formalised wrapper would only be required if non web-enabled services require integration.

Technical Architecture: The adoption of the Web services model also plays a very strategic role regarding openness, interoperability, and integration of the e-CKMI. The e-COGNOS team used WSDL to specify the services that form the e-CKMI Application Programming Interface (API) as well as the services provided by the end users' applications that have to be integrated into the e-CKMI. Having the WSDL file describing a given web service it is easy to produce the web client able to invoke that service. Thanks to this mechanism, all the public services provided in the e-CKMI API are available to any web application in the same way that the e-CKMI interoperates with any other web application.

The Java language was chosen in e-COGNOS as it is platform independent and freely available. The e-COGNOS repository contains several databases holding the Knowledge Representations (KRs), the e-COGNOS ontology, the Ontology Server database, to name a few. Postgress, MySQL, and basic file systems were also used.

The technical architecture (see Fig. 6), which encapsulates the software components and functionalities required to support the conceptual architecture. Both *e-Cognos manager* and *e-Cognos portal* services are offered for end users and system administrator. While these functionalities are conceptually independent, the access is provided via one single portal, with the distinction being made by means of user access rights. This portal application relies mainly on the JSP technology and uses the Jakarta Struts framework to separate presentation from business logic via a MVC (Model View Controller) architecture. Furthermore, Remote Method Invocation (RMI) may be used directly in certain instances to communicate with the *e-CKMI Kernel*.

- The *e-CKMI ServiceManager* has been implemented as a web service itself, which is accessible through RMI/SOAP from client applications (in this case, both User Portal and Manager). It provides the bridge between the client applications and the *KM Core Services*, with support of both *e-Cognos UDDI registry* and *e-COGNOS SOAP client/server*. These two form the core infrastructure of e-CKMI since they represent the part that allows us to register and use *KM Core Services* or *External Services*.
- The *Extractor* service enables users to extract a representation of a knowledge item in terms of

ontological concepts. The result of this extraction will be to make the knowledge item available for manipulation within the e-CKMI via its ontological representation. It will also make the item available for indexing.

- The *Indexer* service handles the indexation of the KRs stored within e-CKMI.
- The *Profiler* service creates and handles a mechanism to automatically create a profile of each user to be used to disseminate the acquired knowledge based on the preferences and habits of the users.
- The *Searcher* service enables the user to perform searches across knowledge items. The API presented by this package will provide methods for coordinating searches and facilitating the retrieval of knowledge.
- The *Discoverer* service allows the user to search for knowledge and make it available to the system. This will be knowledge that was not previously represented in, or known about, by the system. For example, the process of knowledge discovery could be brought about by searching the Internet for knowledge not previously known about, by either the user or the e-COGNOS system.
- The *Maintenance* service maintains consistency amongst the knowledge items represented in the e-COGNOS system. The *Ontology service* provides the functionality required to make the selected ontology available to the other e-COGNOS services which may require it. It helps to create the indexes by taking a list of terms that are mapped against the ontological entities and generating a list of *ontological indexes*.
- *Disseminator* service enables the dissemination of knowledge to other users of the system.

7. KM USING e-COGNOS PLATFORM

As explained in the functional architecture of e-COSER and e-CKMI, e-COGNOS platform offers a set of complementary KM tools. These tools were developed based on input from industry which identified some of the most typical KM scenarios normally encountered in their organizations. The following sections provide a brief description of some of these tools:

User profiling: a commonly repeated KM task is the establishment of user profiles. This allows system administrator to identify the skill sets of various individuals, their requirements, roles and preferences. The development of such profiles are essential for marshalling proper KI's to the individuals during mass e-mailing or advanced searches. Fig. 6a shows the sequence diagram for the profiling scenario.

Indexing: The e-COSer provides two algorithms to perform the processes of indexing new KI's and retrieving relevant KR's in semantic queries:

1. Algorithm 1—Lexical Entries: The algorithm compares ontology concepts to the semantic vector of the query. This creates a list of concepts (LoC) matching the semantic vector. A weight (Wc) is assigned to each matching concept (C) using the following formula:

   $W_c = NK_m / NK_{sm}$

   Where:

   W_c: weight of the concept.

   NK_m: number of keywords that match the concept **C**.

   NK_{sm}: number of keywords in the semantic vector.

2. Algorithm 2—Taxonomy-based weighting: this algorithm uses as input the LoC generated by algorithm 1. This algorithm also uses a relative weighting table (entered by system administrator) called LiaisOnto Parameter Table. The table assigns relative weights (Vp) to concepts based on their location in the taxonomy. It assigns larger weights to lower concepts to reduce the tendency of Algorithm 1 to return root concepts (which are more generic). The algorithm uses the following formula:

   $W_c = W_{bc} * V_p$

Where:

W_c: weight of the concept

W_{bc}: weight of the heavy concept (calculated by the Lexical Entries algorithm)

V_p: value configured in the LiaisOnto parameters table.

For example, let us assume that concept C_1 has a weight W_1 based on algorithm 1 (let us assume that this weight is 0.52). Let us also assume that C_1 is a subset of another concept C_2 which has a W2 of 0.85 (based on algorithm 1). If the administrator decide that a concept would lose 60% of its importance if it moves up the taxonomy (V_p=.4), then algorithm 2 will yield a new weight for C_2= 0.85*0.4 = 0.34. This means that the system will return C_1, not C_2 as was the case with Algorithm 1.

Searching: this is one of the most frequent KM scenarios. Fig. 6.c. shows the sequence diagram for an ontology-based search for KI's. A semantic vector is prepared for the search keywords, the indexer then matchs documents (or KI's) to the search vector.

Knowledge discovery: in this scenario, a user specify a set of web sites, which are of interest, or set up a profile for the KI's of interest. The search and indexing services provide ontology-based lists of relevant new knowledge. This is very important to provide knowledge updates (regarding new codes or products) to users based on their profile/requests.

8. ORGANIZATIONAL DEPLOYMENT

The e-COGNOS platform was implemented (on testing basis) at several European construction companies. To assure relevance to industry needs, the e-COGNOS platform (including the ontology, e-COSer, and e-CKMI) was designed with the following guidelines:

1. Full engagement during the life cycle of the project (especially during requirement analysis): a set of industry experts were in constant contact with the project team to assure inclusion of their input in shaping the final products.
2. Interim assessments: a variety of tools were used to capture formal industry evaluation at three main milestones. This included making presentations to industry experts and documenting their concerns/ inputs/requirements. In addition, a questionnaire was also circulated to other experts to assess the project. This included industry experts in Europe and Canada.
3. Formal evaluation: at the end of the project, the final product was subject to a detailed analysis by leading European construction firms in four countries.
4. Real-time experimentation: this included actual deployment of e-CKMI tools in four European firms, which included full installation and analysis of its performance and comparison with other systems

To assure smooth integration with organizational requirements of KM tools, throughout the development of e-COGNOS platform, (and particularly during the final evaluation), four organizations were asked to rank the importance of the basic three scenarios to their business activities and then compare e-COGNOS products against their existing solutions. Tables 1 and 2 show an excerpt from the results of this evaluation. The following can be observed:

1. There is no agreement on the relative importance of scenarios: this is a reflection of the variety of company market niches, extent of IT deployment in each and the local market requirements.
2. In general, companies are not satisfied with their existing tools. The underlying reason for this is that "they are generic, not construction-specific"—something that limits the semantic management of knowledge.
3. Even though e-CKMI did not outperform all existing systems in all criteria, on average it was perceived to have more potential. This is mainly because it was based on the ontology specific to construction and provided relevant functionalities.

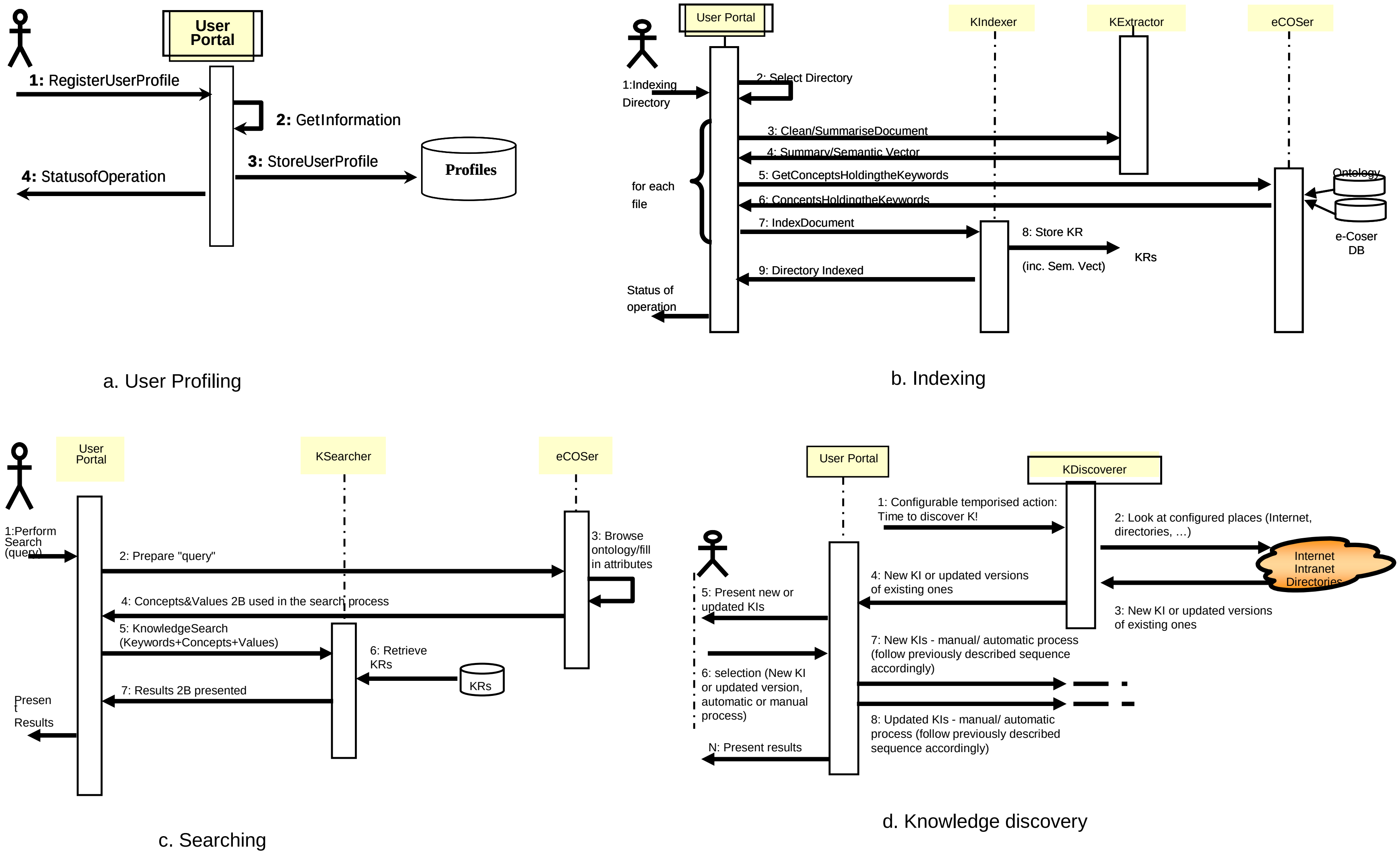

FIG. 6: KM Scenarios

One organisation (hereinafter donated as O) conducted a full scale in-depth analysis of comparing e-CKMI with its existing systems (an in-house document management system and the Athena system). An electronic questionnaire was distributed to staff. The aims of the questionnaire were: (i) to identify the diversity of services currently available to staff and their level of usage of them; and (ii) to specifically examine the usage of Athena which is a document and knowledge management system currently being rolled out for staff use.

The questionnaire sought to establish the usage of the different services, the benefits that staff are achieving and wish to achieve, and the problems and pitfalls that inhibit full exploitation of the facilities available. The questionnaire used both quantitative and qualitative methods to capture both what is happening and the comments of staff on why it is happening. The overall aim is to establish benchmark data which will clarify the benefits that e-CKMI could provide and identify the issues, both technical and organisational, which would need to be addressed if it was to be successfully deployed.

411 responses were received from a total of 1655 staff, which represents a 25% response rate. Responses were received from all grades of staff and all departments and the sample can be regarded as a good cross-section of staff. Employees use a considerable range of systems to store and manage documents electronically. 66% reported storing documents on the hard drive of their PC and 81% reported storing files on a network file system. In both cases, they store a wide variety of types of information. Over 90% of staff stored word and excel files on both their PCs and network file systems. There are also considerable numbers of staff who use both storage systems to keep access and PowerPoint files, CAD/Drawings, scanned images, e-mails and photographs.

It is worth noticing that respondents indicated the following pitfalls of using Electronic Document Management Systems (especially Athena): *it takes too long* (51%), *it means changing our work practice* (23%), and *it is hard to use* (21%). Staff complaints could be categorized as follows:

- Unreliability: computer crashes, instability and slowness of the system.
- Set up time: including installation and conversion of files for storage in Athena.
- Team Agreement: co-operation in the use of the system.
- Access: it is difficult to co-operate with outsiders, and people abroad.
- Linking files: difficulty in building a reliable set of links between files.
- Coverage of all knowledge items: cannot manage some kinds of files adequately (drawings, 3D images, large technical files)

When asked how these pitfalls could be overcome, respondents produced contrasting views. 13 respondents suggested system changes that would improve and standardise the file structures used by Athena and suggested that guidance be issued to ensure that a common approach was used across projects. A group of 10 respondents saw top management edicts as the priority to require people to use Athena so that it became the way for handling documents. By contrast 5 respondents felt either that Athena should not be used (use something simpler, use Expedition etc) or that it should only be used for specific kinds of documents or functions because other services were superior for other purposes.

Within such a backdrop, the organisation conducted a query to compare Athena, e-CKMI and the organisation's own proprietary system. A total of 18 Health & Safety Reminders issued by the organization were read and a series of 12 queries devised based on the content. The queries varied in complexity from simple one or two word searches to complex sentences designed to test concept based search capabilities. For each query, a list of the documents that could be expected to be found was prepared. These varied in number between 1 and 5 depending on the query. Six metrics (see Table 3) were selected in order to help judge the effectiveness of a number of search mechanisms using the 12 queries and the results produced by e-CKMI were considered very good by the end users, as shown in Table 4.

It is true that e-CKMI is not a commercial solution and it was not deemed to be, but the insights provided by the end users evaluation were very encouraging and clearly pointed out the paths to be followed in order to produce a software tool truly adapted to the needs of the construction sector.

9. ANALYSIS AND LESSONS LEARNED

The development and deployment of e-COGNOS platform reveals the following lessons:

Knowledge flow through organizations: throughout the discussions with end users and observation of e-COGNOS deployment, the following patterns of knowledge/learning patterns were observed:

- Feedback knowledge: a good number of employees learn and validate their knowledge through getting feedback from other colleges. This feedback is provided in person, through e-mail, or through formal evaluations.
- Contrasting knowledge: a good number of employees gain knowledge through comparing/contrasting various approaches to problem solving (by other colleagues or through benchmarking competitors).
- Knowledge Reuse: organizations commonly depend on reusing successful strategies from previous project (especially in the design domain).
- Collaborative knowledge discovery: normally most of the valuable knowledge is generated through collaborative setting where people with different backgrounds and skills work together.

To that end, the ontology presented a very promising means as it allowed for effective knowledge representation, storage and access.

User Autonomy: users have great autonomy and, as a result, use a wide variety of services and systems. This means that for any new service to gain acceptance it must offer specific benefits to individual users. It should also blend easily with existing tools. This also emphasises the need for dynamic customization of knowledge tools to fit users' needs. This showed that the use of web services (with their inherent flexibility) is an effective tool. Having knowledge encapsulated in the ontology and then building the web services on top of the ontology was thought to be an effective means for shielding the users form the knowledge modelling/update task (which are left to system administrators and ontology manager). The users were only exposed to the web services, which allowed them to seamlessly use the ontology for the specific tasks at hand.

Efficiency of KM Tools: the users of document handling systems are looking for easy to use ways of managing and sharing documents. At present the electronic systems available to them are not meeting their needs in a suitable fashion, either because the required knowledge is not available on these systems or because their approaches to searching are not very effective. There appears to be a strong association and possible conflict between the sought benefits on document management and searching for knowledge.

The advantages of semantic systems: through ontology, semantic systems were shown to effectively respond to the needs of human-centred KM tools. Ontologies have three main advantages:

- Interoperability: similar to data exchange standards, ontologies provide a platform for interoperability which allows for effective and seamless communication and dissemination of knowledge.
- Object-orientation: similar to entity-relationships and class diagrams, ontologies represent concepts in an object-oriented fashion. In many cases, ontologies are represented in UML (as was the case in e-COGNOS). This allows for easy generation of software system that are based on the ontology and provides for flexibility during ontology updates.
- Knowledge representation: unlike data exchange standards and UML, ontologies encapsulate knowledge through:
    - Taxonomies: building taxonomies creates consistent vocabularies and means for classifying current and future concepts in. taxonomies creates knowledge sub-domains in the form of concept trees.
    - Relationships: relationships link (at various levels) different sub-domains allowing for a polymorphic view of the concepts and their interrelationships.
    - Axioms: using axioms allows for encapsulating the wisdom of humans to define the behaviour/boundary conditions of concepts.

Web services role in collaborative KM systems: by their very nature, KM systems have to support collaborative exchange of documents and, at the same time, allow for customization of services based on user needs. Web services provide a very effective means to assure collaborative and customizable access to KM services.

Cultural issues: staff tend to place documents on systems to permit sharing information with team members, not to share their knowledge with the rest of the organisation. However, unless the knowledge in these documents becomes available across the company, searches of internal knowledge stores may not detect all that the organisation actually knows.

Obstacles to Usage: even if beneficial systems could be deployed, it is unlikely that there would be rapid deployment of KM tools in construction unless a range of obstacles to usage could be addressed. Staff IT competency levels are very variable and search techniques in particular need development. Staff appreciation of benefits is also variable. Achieving knowledge sharing outside projects may be a more daunting target than sharing within projects. Sharing across organisational boundaries may also be a major obstacle.

Work processes: there is evidence that due to the lack of knowledge culture, limited time, and the complexity of existing KM tools, that staff are looking at KM tools as means for document storage and search only. They do not consider using and updating these tools as part of their work (rather, just an IT tool to help manage documents). While it may be easy to start and manage an effective IT-training program to address the issue of IT competency, addressing the usage pattern requires a change to work processes to embed KM tools in the day-to-day work activities of staff.

Many of the findings reflect usage patterns and work practices found by other studies. These findings are not therefore unique to organisation O or to the construction industry. The range of services in use and the low levels of usage of many facilities are common amongst professional ‘discretionary users’. They tend to be active in assessing the ‘benefits’ not just of systems, but of specific facilities, and weigh them up against the ‘costs of use’ (more likely to be effort needed to use than financial costs). Studies of CSCW (computer supported collaborative work) (Olson and Olson 1997) also show that it is difficult to obtain disciplined collaboration to sustain effective use of shared systems. They also find that work teams show great concern about controlling access so there is only internal sharing of working papers, i.e. no external access. Studies of search behaviour show that most users employ rather broad search questions and suffer from irrelevant results. They also show that, when a user is searching a more limited dataset, they much prefer to browse the categories and links rather than use a search engine. Another finding that is widely reported is that when users are searching for knowledge, they prefer to go to a human source with whom they can discuss the issue before they would search an electronic store.

Future developments in the e-COGNOS platform are to include:

- support the creation and use of a “taxonomy of relations” to be applied to the “taxonomy of concepts”. Up to now the backbone of the e-COGNOS ontology is a pure taxonomy that only relies on taxonomical relations to structure the tree. The idea to be explored is to have a pair of taxonomies to represent concepts and relations, bearing in mind that the taxonomies of relations is applied directly to the taxonomy of concepts since each relation node knows exactly what types of concept nodes it can relate;
- layering the ontology: the ontology is expected to grow in terms of size and complexity. Future development will focus on proving various versions of the ontology with varying degrees of complexity (and depth) ;
- extend the method of calculating ontological weights taking into account the “web” of relations that can be linking the heaviest concepts in the query. Currently only the taxonomical relations are used to calculate the ontological weight.
- To evaluate how feasible is to map the e-COGNOS ontology with other ontologies construction-specific.

Finally, the FUNSIEC project (www.funsiec.org) has been launched to investigate how feasible is to build semantic mappings the “Semantic Resources” (SRs) construction-oriented in order to allow for seamless exchange of knowledge among these systems. Semantic resources refer to available semantic systems in the construction domain. This includes thesaurus, taxonomies, and ontologies and the systems built on top of them. Mapping semantic entities, even if they are formally defined, is a great challenge and involves three main aspects (structure, syntax, and semantics). Very often, this means to measure a pair-wise similarity between entities and compute the best match for them (Euzenat et al. 2004).

Initially, FUNSIEC selected four SRs, namely the IFC model, the ISO DIS 12006-3, the bcBuildingDefinitions taxonomy produced by the eConstruct project, and the e-COGNOS ontology. The FUNSIEC quest is to provide an answer to this question: is it feasible is to identify and establish semantic mappings among those SRs? If the answer is yes, FUNSIEC should devise a methodology to support this work, on one hand and on the other hand, the project must produce the first attempt of such mapping. This means, to build the respective meta-model and model of the Open Source Infrastructure for the Construction Sector (OSIECS) mapping the SRs abovementioned (Lima et al. 2005).

As part of this project, the so-named FUNSIEC Semantic Experience Centre (FSEC – www.funsiec.org/fsec) was deployed aiming to be an instrument in the education process for showing, using and explaining how SRs can be used to support e-business activities in Construction. The primary focus of the FSEC is on the business aspects and work processes. This is to be achieved through a variety of means (demonstrations, films, mock-ups, or any other sort of tool) particularly facilitating and encouraging *hands-on* experience with the SRs.

10. CONCLUSIONS AND FUTURE WORK

The paper presented a summary of the development and implementation of the e-COGNOS platform. The e-COGNOS platform is the first semantic system for managing knowledge I n the construction domain. It was developed and implemented through collaboration between researchers and leading European contractors. The e-COGNOS platform implemented an ontology-based system for knowledge management in construction. A set of web services have been developed to support the creation and update of the ontology, support frequent knowledge management activities (such as dissemination and discovery), and managing users (profiling their needs and roles).

The use of semantic (ontology-based) systems for knowledge management provides two fundamental advantages:

- the development of the ontology itself provides a formal (and machine-readable) representation of domain/organisational knowledge
- and, using the ontology for supporting knowledge management activities provides users with an effective and semantic means for accessing and documenting knowledge.

The lessons learned form the e-COGNOS implementation indicate a clear need at the industry for more effective KM tools. Such tools have to be built to adapt to user needs, which indicate that web services could have a major role in the future development of KM tools in the construction industry. The bigger challenge, however, remains in the areas of KM integration in technical and business processes and in human education in KM best practices.

The question for future research in this domain, therefore, include addressing semantic interoperability amongst different ontologies that are being developed in the construction domain, fuller analysis of the human and cultural aspects of semantic systems use in construction, and the linkage between semantic systems (and KM in general) to competitiveness and returns on investments (making the case for KM).

Future developments of the e-COGNOS platform will include focus on allowing the integration of additional (customizable) taxonomies in the e-COGNOS ontology; layering the ontology to allow users to deploy only certain parts of the ontology; and focusing on the educational and business aspects of semantic KM (through the FUNSIEC project).

11. ACKNOWLEDGEMENTS

The authors would like to thank the e-COGNOS partners for their contributions during the project development as well as the financial support from the European Commission under the IST programme.

12. REFERENCES

Aziz Z, Anumba C, Ruikar D, Carrillo P and Bouchlaghem D (2004) Semantic web based services for intelligent mobile construction collaboration, ITcon Vol. 9, Special Issue Mobile Computing in Construction , pg. 367-379, http://www.itcon.org/2004/26

Björk, B.-C., Löwnertz K., and Kiviniemi A. (1997) ISO DIS 13567 - The Proposed International Standard for Structuring Layers in Computer Aided Building Design, ITcon Vol. 2, pg. 32-55, http://www.itcon.org/1997/2

CEN/ISSS (2004). European eConstruction Meta-Schema (EeM), CEN Workshop Agreement – CWA3. Documents produced by the CEN/ISSS eConstruction Workshop, Brussels.

CIRIA (2000). Applying Knowledge Management to the Construction Industry: a workshop report, *Construction Productivity Network* (CPN), London, UK.

Cooper, R. G. (1983). "A process model for industrial new product development", IEEE *Transactions on Engineering Management* 30 (1).

Cooper G, Cerulli C, Lawson B R, Peng C and Rezgui Y (2005) Tracking decision-making during architectural design, ITcon Vol. 10, pg. 125-139, http://www.itcon.org/2005/10

Davenport, T. H. and Prusak, L. (1998). "*Working Knowledge - How Organizations Manage What They Know"* Harvard Business School Press, Boston, Massachusetts.

Eason, K.D., Yu, L. and Harker, S.D.P. (2000). 'The use and usefulness of functions in electronic journals: the experience of the SuperJournal Project", *Program*, Vol 34(1).

Eason, K.D. and Harker, S.D.P. (2000). "Psychological Processes in the use of Electronic Journals", *UKSG 23rd Annual Conference*, Keele, Germany.

Eason, K.D., Richardson, S, Yu, L. (2000). "Patterns of use of Electronic Journals", *Journal of Documentation*, Vol 56(5).

e-COGNOS (2003). The e-COGNOS official homepage: http://www.e-cognos.org.
Ekholm, A. (1996). "A conceptual framework for classification of construction works." *ITCON.*

Euzenat J., Le Bach T., Barrasa J., Bouquet P., De Bo, J., and Dieng R. (2004). "State of the art on ontology alignment – Knowledge Web project, realizing the semantic web", IST-*2004-507482 Programme of the Commission of the European Community*.

Fensel, D. (2003). "Ontologies: Silver Bullet for Knowledge Management and Electronic Commerce". Springer-Verlag,

Gruber, T. (1994). Toward Principles for the Design of Ontologies Used for Knowledge Sharing. IJHCS, 43 (5/6): 907-928.

Guarino, N. and Welty, C. (2000). *"Towards a methodology for ontology-based model engineering"*, *In Proceedings of ECOOP-2000 Workshop on Model Engineering. Cannes, France*.

IAI (2004). The International Alliance for Interoperability web site, http://www.iai-international.org/iai_international/

ISO (2002). ISO/DIS 12006-3 – Building construction Organization of information about construction works — Part 3: Framework for object-oriented information exchange, http://www.icis.org/tc59sc13wg6/WG6-104%20ISO_PAS_12006_3_VERSION_2X.pdf

Katanuschkov, P., Gehre, A., and Scherer, R. J. (2002). "An engineering Ontology framework as advanced user gateway to IFC model data." *Proc. of the European Conference on Product and Process Modeling*, Prortoroz, Slovenia 9-11 September 2002.

Kazi A. S., Hannus M. and Charoenngam C. (1999). An exploration of knowledge management for construction, Proceedings of the 2nd International Conference on CE in Construction (CIB Publication 236), M. Hannus et al. (eds.), Espoo, Finland, 25-27 August, 247-256.

Lassila, O and Adler, M. (2003)"Semantic Gadgets: Device and information interoperability", *Ubiquitous Computing Environment workshop*, Cleveland, OH, USA

Lima C., Fies B., Zarli A., Bourdeau M., Wetherill M., Rezgui Y. (2002). "Towards an IFC-enabled ontology for the Building and Construction Industry: the e-COGNOS approach", *eSM@RT Conference* , Salford, UK, 18-21 November 2002.

Lima C., El Diraby T., Fies B., Zarli A., Ferneley E. (2003a). “The e-COGNOS project: current status and future directions of an ontology-enabled IT solution infrastructure supporting Knowledge Management in Construction”, *Construction Research Congress*, ASCE, Honolulu, Hawaii.

Lima et al. Lima, C., Stephens, J., Bohms, M. (2003b). “The bcXML: Supporting eCommerce and Knowledge Management in the construction industry”, *ITCON*, Vol. 8.

Olson G.M. and Olson J.S. (1997). “Research on computer Supported Cooperaative Work”, *In Helander, M.G., Landauer, T.K., and Prabhu, P.V. (Eds). Handbook of Human-Computer Interaction,* Elsevier, Amsterdam.

Pezzini, M. (2001) "*The Need for Web services Standards*", Gartner Group, available on-line at: http://www3.gartner.com/Init

Staub-French, S., Fischer, M., Kunz, and Paulson. (2003) “An ontology for relating features with activities to calculate costs.” J. *of Computing in Civil Engineering,* ASCE. Vol. 17 (4).

Weise M, Katranuschkov P, Liebich T and Scherer R. J. (2003) Structural analysis extension of the IFC modelling framework, ITcon Vol. 8, Special Issue IFC - Product models for the AEC arena , pg. 181-200, http://www.itcon.org/2003/14

Welty & Guarino 2001, Welty, C. and Guarino, N., 2000. *Supporting ontological analysis of taxonomic relationships*. Available at http://www.ladseb.pd.cnr.it/infor/Ontology/Papers/DKE-2001.pdf.

Wetherill M., Rezgui Y., Lima C., Zarli A. (2002). “Knowledge management for the construction industry: the e-cognos project”, *ITCON, Vol. 7, Special Issue ICT for Knowledge Management in Construction*.

Whelton M, Ballard G, Tommelein I D (2002) A knowledge management framework for project definition, ITcon Vol. 7, Special Issue ICT for Knowledge Management in Construction , pg. 197-212, http://www.itcon.org/2002/13

TABLE 1: Summary of assessment of functionalities (knowledge manager perspective)

e-COGNOS Field Trial Questionaire	Priority			Existing Tools					Tested (e-COGNOS) Tools				
				Availability		Quality			Availability		Quality		
Functionality	L	M	H	Y	N	L	M	H	Y	N	L	M	H
Knowledge extraction													
Crawl KIs (databases, documents)		x		x			x		x		x		
Extract content, meta-data, named entities and index (.pdf, .dwg, .doc, .xls, .ppt, ...)			x		x				x			x	
Knowledge classification (analyse / organise) - human based or computer based													
Categorise KIs (mapping and ranking according to ontology)		x		x		x			x		x		
Cluster (find similarities between KIs))			x		x					x			
Analyse correspondance to profiles (user profiles, habits)			x		x					x			
Knowledge storage													
Search, find and rank (manner)													
Full text search (truncations, spelling corrections, etc.)			x		x				x			x	
- By selected concepts		x			x				x			x	
- Assisted by ontology (guided searches)		x			x				x		x		
- By similar documents or searches			x		x					x			
- Crawl selected knowledge sources			x	x		x				x			
Search, find and rank (KIs)													
Personalised expertise (skills):			x		x								
- Experts, communities			x		x					x			
Data (facts):													
- Product data, suppliers, contractors, technical data, codes and standards, forms and sheets			x	x			x		x		x		
External and internal reports (topics)		x		x		x			x		x		
Knowledge sharing and assessment													
Publishing of valuable documents (make your solutions available to others)			x	x			x		x		x		
Discussion forums			x	x		x				x			
Ranking of KI items by users			x		x				x			x	
Knowledge dissemination													
Distribution channels on subscription or profiles:													
- Company news	x			x			x			x			
- Project news		x		x			x			x			
- Specialised knowledge			x	x		x				x			
Creation and synthesis of new solutions													
(i.e. use related information to create answers)			x		x					x			
Knowledge maintenance													
Crawl dedicated knowledge sources and watch for changes			x	x		x				x			
- Measure impact of change		x			x					x			
- Automatic notification of change to impacted KIs		x			x					x			
- Automatic notification of relevant change users			x		x					x			
User profiles													
Personalised user interfaces			x		x					x			
Private configurable work spaces		x		x		x				x			
Shared virtual work spaces		x			x					x			
System administration													
Access and rights control			x	x			x			x			

TABLE 2: Summary of assessment of functionalities (development manager perspective)

e-COGNOS Field Trial Questionaire	Priority			Priority			Existing Tools					Tested (e-COGNOS) Tools				
							Availability		Quality			Availability		Quality		
Functionality	L	M	H	L	M	H	Y	N	L	M	H	Y	N	L	M	H
Knowledge extraction																
Crawl KIs (databases, documents)		x			x			x					x			
Extract content, meta-data, named entities and index (.pdf, .dwg, .doc, .xls, .ppt, ...)			x		x			x				x		x		
Knowledge classification (analyse / organise) - human based or computer based																
Categorise KIs (mapping and ranking according to ontology)		x				x		x					x			
Cluster (find similarities between KIs))			x		x			x					x			
Analyse correspondance to profiles (user profiles, habits)			x		x			x					x			
Knowledge storage																
Search, find and rank (manner)																
Full text search (truncations, spelling corrections, etc.)			x			x		x				x		x		
- By selected concepts		x			x			x				x		x		
- Assisted by ontology (guided searches)		x			x			x				x		x		
- By similar documents or searches			x			x		x				x		x		
- Crawl selected knowledge sources			x			x	x		x				x			
Search, find and rank (KIs)																
Personalised expertise (skills):			x			x		x								
- Experts, communities			x			x		x					x			
Data (facts):																
- Product data, suppliers, contractors, technical data, codes and standards, forms and sheets			x			x	x		x				x			
External and internal reports (topics)		x			x		x		x			x				
Knowledge sharing and assessment																
Publishing of valuable documents (make your solutions available to others)			x			x	x		x			x		x		
Discussion forums			x			x		x					x			
Ranking of KI items by users			x			x		x				x			x	
Knowledge dissemination																
Distribution channels on subscription or profiles:																
- Company news	x			x			x		x				x			
- Project news		x			x		x		x				x			
- Specialised knowledge			x			x	x		x				x			
Creation and synthesis of new solutions																
(i.e. use related information to create answers)			x		x			x					x			
Knowledge maintenance																
Crawl dedicated knowledge sources and watch for changes			x			x	x		x				x			
- Measure impact of change		x			x			x					x			
- Automatic notification of change to impacted KIs		x			x		x		x				x			
- Automatic notification of relevant change users			x			x		x					x			
User profiles																
Personalised user interfaces			x			x		x					x			
Private configurable work spaces		x			x			x					x			
Shared virtual work spaces		x			x			x					x			
System administration																
Access and rights control			x			x	x		x				x			

TABLE 3: Measurement goals, questions and metrics

Measurement goals	***Measurement questions***	***Measurement metrics***
Do they satisfy business requirements?	**Speed:** Can you find data fast enough to satisfy your requirements?	Percentage of positive answers: Y/N
	Intuitiveness: Does the system help you to use the system, i.e. does it flow in natural stages, give hints etc?	Percentage of positive answers: Y/N
	Functionality: Can you find the answer to your question / relevant info within the first five search results returned?	M1.4: Percentage of positive answers: Y/N
	User Satisfaction: Does the system speak your language? Are words, phrases and concepts familiar to you?	Users satisfaction in using the system: 1 to 5 (V. Satisfied to V. unsatisfied)
Analyse knowledge quality in the system	**Relevancy:** Is the knowledge retrieved relevant?	Percentage of positive answers by staff: Y/N

TABLE 4: Comparison showing the success of the search queries between the search mechanisms

Query	Records expected to be found	Actually Found			
		Proprietary System	Athena Explorer	Athena Web	e-COGNOS
CSCS (basic search)	2	2	2	2	1
Traffic management (phrase search)	1	1	1	1	1
Temporary works scaffold (basic search)	3	1	1	1	1
Temporary works scaffold (plain English search)	3	0	-	-	-
Risk assessment (phrase search)	4	3	3	3	3
Safety aspects of lifting operations (plain English search)	3	0	3	3	3
Examples of innovation in health and safety (basic search)	1	0	1	1	2
Examples of innovation in health and safety (plain English search)	1	1	-	-	-
Innovation health and safety (exact phrase)	1	0	-	-	-
Innovation health and safety (plain English search)	1	0	-	-	-
Health and Safety Inspector visit to site (plain English)	2	0	2	1	2
What is the role of an Appointed Person (plain English)	1	0	1	0	0
What are the lessons learnt by health and safety (2001 and 2002)?	2	0	2	0	2
What should I know when setting up temporary site accommodation?	1	0	1	0	1
What new legislation and guidance has been issued	3	1	3	0	2
What are the things that HSE are most concerned with?	2	0	1	0	0