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Semantic-Web Supported Knowledge Management System: An Approach to Enhance Collaborative Building Design

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Abstract

This paper focuses on a lightweight ontology-based knowledge management system, which is a main component of IT-CODE, a Semantic Web based virtual workspace for enhancing the collaboration at an early building design stage. Technologies with respect to de facto standards that are proposed by industry group W3C are implemented to develop this knowledge management system. Resource Description Framework (RDF) associated with its Schema (RDFS) is selected as ontology language of the system. RDF(S) with its embedded reasoning techniques provides a rich set of constructs to facilitate the generation of ontologies so that the annotated information can be machine readable. Initiatives taken in the building industry for the evolution of the Semantic Web will be overviewed in this paper. Potential benefits offered by the RDF(S)-based knowledge management system to the building industry will be explained. Approaches of how the knowledge is represented in RDF-based ontology, is shared and retrieved among actors participating in the early design phase of a building project will also be described and illustrated. The paper will conclude with a description of how the early design phase may benefit from IT-CODE and its innovative knowledge management system.

Keywords: semantic-web, RDF(S), knowledge management system, ontologies, collaborative design

1. Introduction

1.1 Background

Decisions made at the early stage of a product development process, the design process, have severe influences on the quality of the product (Cohen, 1995). This is a common phenomenon of projects in any domain, including the building sector (Boverket & BFR, 1994; Formoso et al., 1998) because design is a decision instrument to express product features and production information (Formoso et al., 1998). To improve the design process performance, numerous initiatives have been taken including the partnering concept with its focus on stimulating collaboration amongst the stakeholders from the beginning of a project. Establishing shared value particularly in the context of project related knowledge tends to improve collaboration amongst stakeholders, and therefore allows them to make fast and accurate decisions at the early stage of design in order to reduce the potential negative costly impact on the later stages.

Developing a mechanism to manipulate (capture, store, search, retrieve) knowledge generated from experiences has been of interest since the realization that people and knowledge are the most important strategic resources of an organization (Fruchter, 2002). The fast developing information and communication technology (ICT) tends to expedite the research progress in this area by contributing ICT tools that comprises collaborative features such as co-editing, co-browsing, etc. Systems enhanced with technology as such have been used by various professional domains, including the building sector, tempting to manage the existing information base.

1.2 Problem Definition

The early stage of a building project is usually referred to as activities that start from client briefing to conceptual design and are inherently iterative. Data and information generated at this stage, such as briefing notes and sketches are mainly informal and not well structured but important to reflect the tacit design knowledge and possibly documented as design rationale. Such weakly structured information is not less important than the structured one such as the final drawings and reports that are generated at the end of every meeting. Likewise the tacit and explicit knowledge (Nonaka & Takeuichi, 1995), it is an uneasy task to integrate both the weakly- and well-structured information from the perspective of traditional knowledge management (Fensel et al, 2002).

The building industry is very project-oriented in nature, and it is organized on actor streams wherein actors are involved in several projects at the same time (Zarli et al, 2002). Actors involved in the same project are sometimes thousand miles apart and practicing different working methods in accordance with their respective roles. In addition, most projects can be characterized as virtual organizations that are only established for the duration of a contract with temporary and often short-term business relationships (Zarli et al., 2002). All of these factors have created the dilemma upon the building sector that extra resources are required respectively to manage each project. Consequently, the project related machine stored knowledge would no longer be contained in one centralized repository but distributed in heterogeneous databases that belong to different individuals, discipline groups, project-teams and organizations. Even though the concurrent ICT enables the formation of virtual project teams that can work across geographical and time constraints through virtual workspaces, integrating the heterogeneous information sources particularly ones that contain weakly structured information remains an uneasy task in the building sector. The widely use of low-level technologies mostly adhering to hyperlinks and keywords search (Ding et al., 2003) and lack of meta level data structures (Christiansson, 1998) is the main reason behind this non-integrating phenomenon.

1.3 Aims and Objective

The above-delineated shortcomings have motivated the necessity of an innovative knowledge management system. A hypothesis can therefore be formulated that a Semantic Web based knowledge management strategy is applicable to the building sector to overcome the dilemma of information and knowledge integration in this domain and furthermore significantly extend the collaboration support amongst project stakeholders.

This article focuses on a knowledge management system built on lightweight ontologies to support the motivation of the building sector with respect to the change of web technologies that evolve from the WWW to the concurrent Semantic Web.

2. **State-of-the-art Review**

2.1 Semantic Web and ontologies

The Internet associated with its most popular application, the WWW, provides interconnected infrastructures that are commonly used to facilitate the accessibility of digital resources. However, this web technology has severe shortcomings that arise from its simple underlying structures and protocols. The current WWW works well for posting and rendering all kinds of web contents but provides very limited support for processing them. This is because most web contents are stored in natural language chunks, which makes them very much dependent on the human users during search, access, extraction, interpretation and processing. Meanwhile, the growing use of WWW has increased the difficulty to manipulate the exponentially increasing amount of information. In response to this, the vision of a Semantic Web was created by Tim Berners-Lee in order to enable automated information access and use based on machine-processable semantics of data. Semantic Web was defined by him as "*an extension of the current web in which information is given well defined meaning, better enabling computers and people to work in co-operation*" (Berners-Lee et al., 2001). To accomplish this vision, efforts to link the existing web contents to semantic descriptions followed by the creation of a set of applications that can utilize this newly created metadata are desperately in need, which thus stimulate a new research horizon (Fensel et al., 2002; Semaview, 2002).

Ontologies are decentralized vocabularies of concepts and their relations to which the existing web contents can refer. These decentralized vocabularies not only define the meaning of web page contents but also the contents of other information resources, including documents (paper-based) and databases. Ontologies are therefore the kernel of the Semantic Web that allow computers to better categorize, retrieve, query and deduce information from the WWW than the current web technology (Ding et al, 2003; Fensel, 2001).

The concept of ontology applied in Artificial Intelligence is to facilitate knowledge sharing and reuse (Fensel, 2001). Ontology is claimed able to provide a shared and common understanding of a domain so that people and various application systems can communicate across the widely spread heterogeneous sources (Maedche et al., 2001). As defined by Gruber (Gruber, 1993), ontology is a formal explicit specification of a shared conceptualization. Thus, it should be machine-readable (Ding et al., 2003; Fensel, 2001). In general, ontology is a graph which nodes represent concepts or individual objects while arcs represent relationships or associations among concepts (see Figure 1). The ontology network takes account of properties and attributes, constraints, functions, and rules that govern the behavior of the concepts (Fensel, 2001). In this respect, ontologies are useful to organize and share information while offering intelligent means for content management as well as enhancing semantic search in distributed and heterogeneous information sources (Filos, 2002; Fensel et al., 2002). In accordance with Maedche (Maedche et al., 2001), establishing domain specific ontologies is important for the success and proliferation of the Semantic Web. Thus, it should also be appropriate to apply such a strategy to the domain of building sector to support better information as well as knowledge sharing amongst the geographically distributed stakeholders.

In view of the increasing importance of ontologies, international research in this arena, which has been conducted during the last decade has presented promising results in the creation of ontology languages (W3C, 2002; DAML, 2002; OWL, 2003), ontology editors (Protégé; Fillies, 2001), reasoning techniques and development guidelines (W3C, 2002). To date, the applications of ontologies are mainly found in e-commerce. A number of EU-funded projects have been undertaken to address knowledge technologies in the context of virtual organization and business collaboration wherein application of ontologies is the fundamental interest. Amongst them, for example, are ONTOWEB which is a thematic network on ontologies-based information exchange for knowledge management and e-commerce (OntoWeb, 2003), COMMA which aims at implementing a corporate memory management framework based on agent technologies, OnToKnowledge (On-To-Knowledge, 2002) that aims at developing tools and methods for supporting knowledge management relying on sharable and reusable knowledge ontologies. By considering the typical collaboration pattern, it is aware that the building sector is also committed to virtual-organizational business relationships, which is mainly project oriented. By bearing resemblance as such to the e-commerce sector, an argument was made that the practicing strategy in e-commerce to improve business collaboration via knowledge sharing is probably applicable to the building sector.

2.2 Evolution of Semantic web in the Building Sector

To maintain its competitiveness, the building sector must progress in parallel with the e-commerce sector to face the challenges of paradigm shift with respect to the use of the innovative ICT as well as the strategy of ontologies. To date, the favorable collaboration ICT tools in the building sector are the project extranets (project websites), workflow management tools and groupware application for collaborative working.

Project extranet builds on client-server and web browser technology to enable distributed project team members to share, view and comment on project-relevant information. This tool is still widely implemented though limitations from its purely document-centric characteristic and limited workflow support have been identified. To overcome the limitations of project extranet is somehow necessary to accommodate the increase of information generated throughout the building life, in particular in the early creative design phase wherein fragmented design knowledge capture is of importance. The use of diverse professional languages impairs communication amongst stakeholders while provoking them to the possibilities of misunderstanding. After being aware of the potential impact, the building sector has taken numerous initiatives to broaden the horizon of communication capabilities that are supported by the Internet, and therefore lead to a change of paradigm.

In this aspect, several EC funded projects have been conducted to provide the building sector a stepping-stone on the path of paradigm-shift. For example, Diversity, which is a project that aims at supporting and enhancing concurrent engineering practices through allowing teams based in different geographical locations to collaboratively design, test and validate shared virtual prototypes (Christiansson et al., 2002), and e-Construct, a project with the aim to improve internet-based communication in e-Commerce and e-business, in the context of communication across national and organizational barriers. Solutions for transferring and sharing knowledge across ICT systems are therefore the focus of e-Construct. To achieve the objective, a common communication-oriented language, namely bcXML has been defined based on Extensible Markup Language (XML) with building construction meaning aimed at e-Commerce transactions (e-Construct, 2001). E-COGNOS, which aims at offering a generic, modular and open solution for knowledge management in the context of collaboration between actors in a construction project (e-COGNOS, 2001) started in year 2001. To summarize, the insights of these examples imply that there is an evolution tendency from the *document centric* Internet to a *meaning centric* Semantic Web. This shift in focus may meet the requirement of knowledge management practices in the building sector, which is mostly informal and people- centered wherein abstract concept and meaning are of interest.

2.3 Application of Semantic Web in Knowledge Management

The impact from the Internet and the phenomenon of globalization has resulted in many organizations and project teams to be increasingly geographically dispersed. To cope with this paradigm change, the organizations require knowledge management tools that enable better understanding of the distributed organizational and project-specific digital knowledge and its corresponding containers, thus, enabling efficient collaboration as well as knowledge capture, representation and user adapted access. Most of the currently available knowledge management tools have limitations as described below though they were designed to deal with operations of relevance to the knowledge lifecycle of a particular organization.

- Information searching is mainly based on keywords search, which may retrieve irrelevant information due to term ambiguity and omit important relevant information when it is stored under different keywords (Ding et al., 2003)
- Manual efforts such as browsing and reading remain the main methods to extract relevant information from textual or other representations. The currently available software agents fail to integrate information from different sources (Ding et al., 2003).
- Maintaining large repositories of weakly structured information remains a tough and time-consuming task (Ding et al., 2003).

High degree of automation and scalability in performing tasks with respect to the above mentioned limitations are expected from exploiting the Semantic Web technologies in the arena of knowledge management. The up scaling of the traditional business arena together with the implementation of efficient support for knowledge management and collaboration puts strains on the existing organizational structure. A leap from the conventional knowledge management system to one built on Semantic Web will facilitate the process (Christiansson, 2003). The Semantic Web based knowledge management system will be able to keep weakly structured collections consistent, to generate information presentations from semi-structured data, and to create semantics of these collections and data which is both machine-accessible and machine-processable (Ding et al., 2003; Fensel et al., 2002). To accomplish this, the semantics must be represented based on formal ontologies (Fensel, 2001) with the use of ontology languages that have been developed since the past decades. The basis of most of these developed or developing ontology languages is the one called Resource Description Framework (RDF), which is the outcome of industry group W3C (W3C, 2002). RDF is a specification for defining machine-understandable metadata while its schema (RDFS), provides a simple mechanism for defining ontologies. With regard to ontologies, RDFS provides two important contribution: a standardized syntax for writing ontologies and a standard set of modeling primitives such as instance-of and sub-class-of relationships (W3C, 2002), see also Figure 1. An RDF document consists of a variable number of triples, each of which is composed of *subject, predicate and object*. Triples exist independently without concerning the order in which they occur. The use of RDF and their associated RDFS-defined ontologies provide the computer with information to discover the meaning of the data. A new semantic markup language, OWL (Web Ontology Language) that is developed as a vocabulary extension of RDF and is derived from the DAML+OIL (DAML, 2002) is in the process of being standardized (W3C, 2003).

3. Methodology

A semantic web based knowledge management system is being developed as one of the components of IT-CODE, a virtual workspace environment that aims at enhancing collaboration in the early design phase of a building project (see Lai et al, 2002). The main objective of this knowledge management system is to support decision making in multi-actors environments wherein information is archived in heterogeneous sources. The system is primarily developed to integrate pieces of information generated at the iterative early design stage, to provide fast and precise semantic search, and to capture the intent and rationale behind decisions made particularly during the early design process. The present state of the developing prototype system, which will be presented hereinafter, is only capable of the former two functionalities.

A retrospective case study was carried out to populate the prototype system with a significant amount of real practice data. Survey interviews were conducted with several key stakeholders of a nearly completed building project. The interviews were adopted as the retrospective case study, to investigate the envisaged performance of the mechanism used in the case. The interviews were considered as a departure point to gather requirements from potential users (here referring to the project stakeholders) for future research. Case study was used as a tool to collect historical data in regard to the decision-making process, project information management and flow, as well as project documentation and communication.

Project web was the mechanism used in the case as a means to collect the project-relevant information. However, only structured information, such as design drawings and meeting minutes were available in this information pool. The interviewees delineated the limitations of project web in regard to the effectiveness of information dissemination. Information was categorized based on the preferences of the web master, and was archived under different electronic file folders that were created based on the predefined categories. The semi- and unstructured information such as briefing notes, design rationale, and e-mail messages, was not stored in the project web. E-mail messages were collected in another project-owned digital information source while the paper-based information was kept in personal archives such as file cabinets. Telephone was the most commonly used communication means in the project, i.e. the case, to share updated information which context was sometimes the intent behind a decision made. Drawings were generated at every stage with respect to the design change, but only the final version was uploaded to the project web. Briefly, such descriptions reflected the implication of fragmentary communication and information flow. Apart from that, another significant shortcoming of the project web in use is the dependency of inefficient human efforts in processing such as searching, browsing and extracting the archived information.

To cope with the delineated shortcomings, an innovative prototype system was built on ontologies that were defined with RDF Schema (RDFS) (W3C, 2002). RDF and its schema are the de facto standard for expressing simple metadata. A number of recently developed and publicly available RDF tools have made the RDFS the core of the prototype system. Scenarios were used in the design of the early prototype and as a basis for prototype verification through user testing.

Two examples of the scenarios used for designing the early prototype system were outlined as the following:

Say Bob wants to know who all the engineers involved in Project C are. Very quickly, he just input the name of Project C to access the ontologies (RDFS) built. A list of properties that are defined in the RDF schema of Project C is then displayed in the drop-down list box to assist Bob to search the information of interest. By choosing the property named "has-role" and filling in the provided dialog boxes to construct a simple query for narrowing down the search scope, Bob is then displayed the searched result. The result consists of the names of all involved engineers, and their profiles.

Bob now wants to find all documents in regard to space planning that finished before 29/3/2001 of Project B, the stakeholders who contributed in the planning and where these documents respectively are stored. Bob needs to choose the project-specific ontology by inputting the project name, i.e. Project B. His next step is to construct a query by following the user-friendly on-screen instruction. After inputting such information as "Search documents and authors of documents with keyword of space-planning and cut-off date of 29/3/2001" into the appropriate dialog boxes, the demanded answers are displayed associated with the respective URIs (Uniform Resource Identifiers) of the document.

4. The Prototype System

The excerpt of the RDFS whereof the prototype system was built is depicted in Figure 1. The system was developed with high flexibility so that it can accommodate an unlimited amount of new ontologies in the future. Such ontologies should be defined in a way to capture the domain knowledge. The concerning domain in this case was project management of building project based on the historical data of the retrospective case study. With respect to the above-described scenarios, this early prototype system provided functionalities of semantic search of information that was distributed in heterogeneous digital sources. The project-specific ontology consisted of few modular parts, which respectively was ontology, for example the "team-profile ontology" and the "early-design-process ontology"(see also Figure 2) that described another aspect of interest, such as the team profiles and the early design process flow, respectively. The project-specific ontologies are linked with each other to provide the expandable capability of the prototype. The graphical presentation illustrated in Figure 2 shows the modular characteristic of the ontologies network, which each was accessible through the uniquely specified URI (Uniform Resource Identifier). The modular characteristic permitted the scattered information including the existent data and the respective ontologies not to be collected under one central repository.

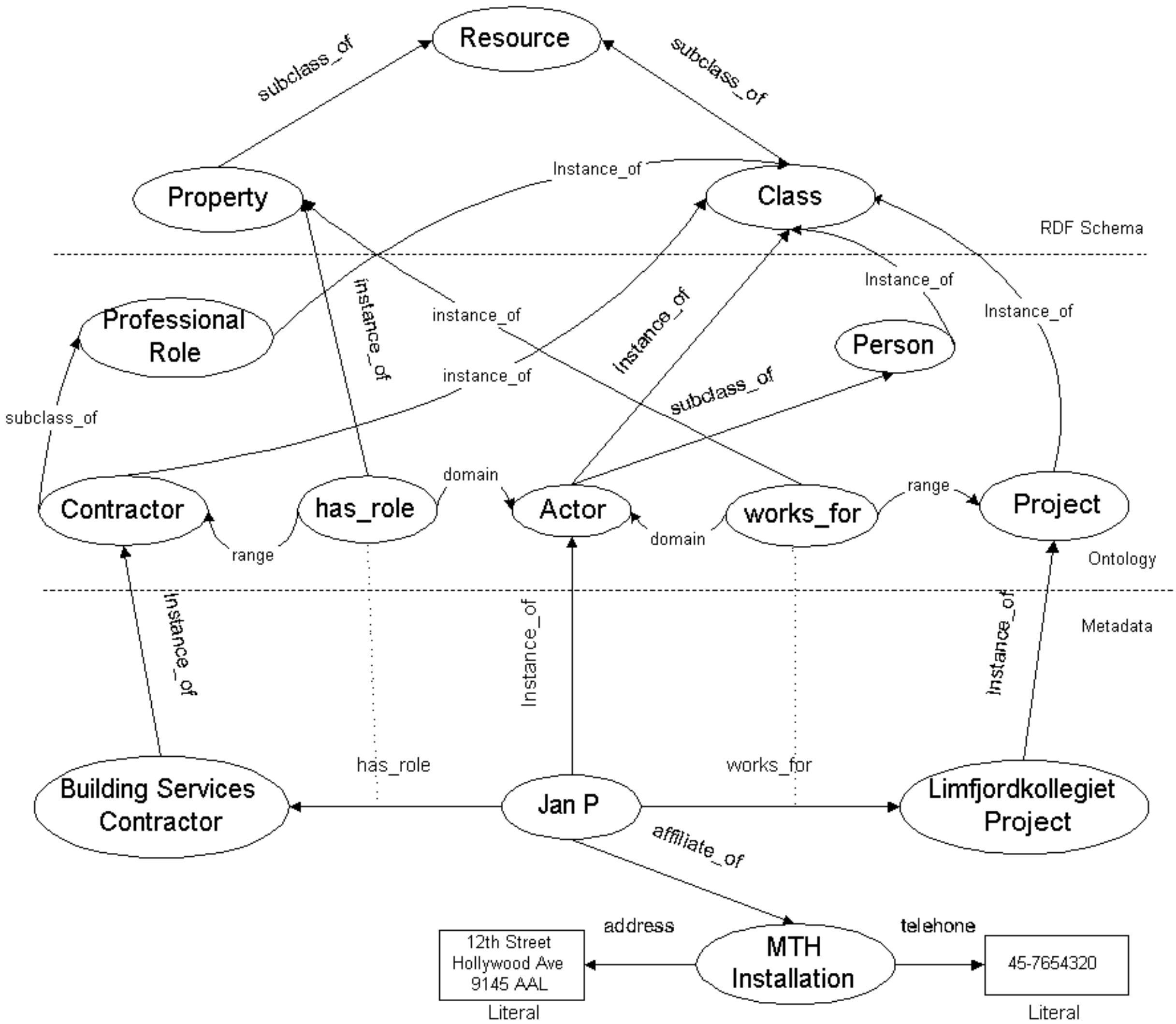

Figure 1: Excerpt of the RDFS based lightweight ontology and RDF based metadata based on the case study

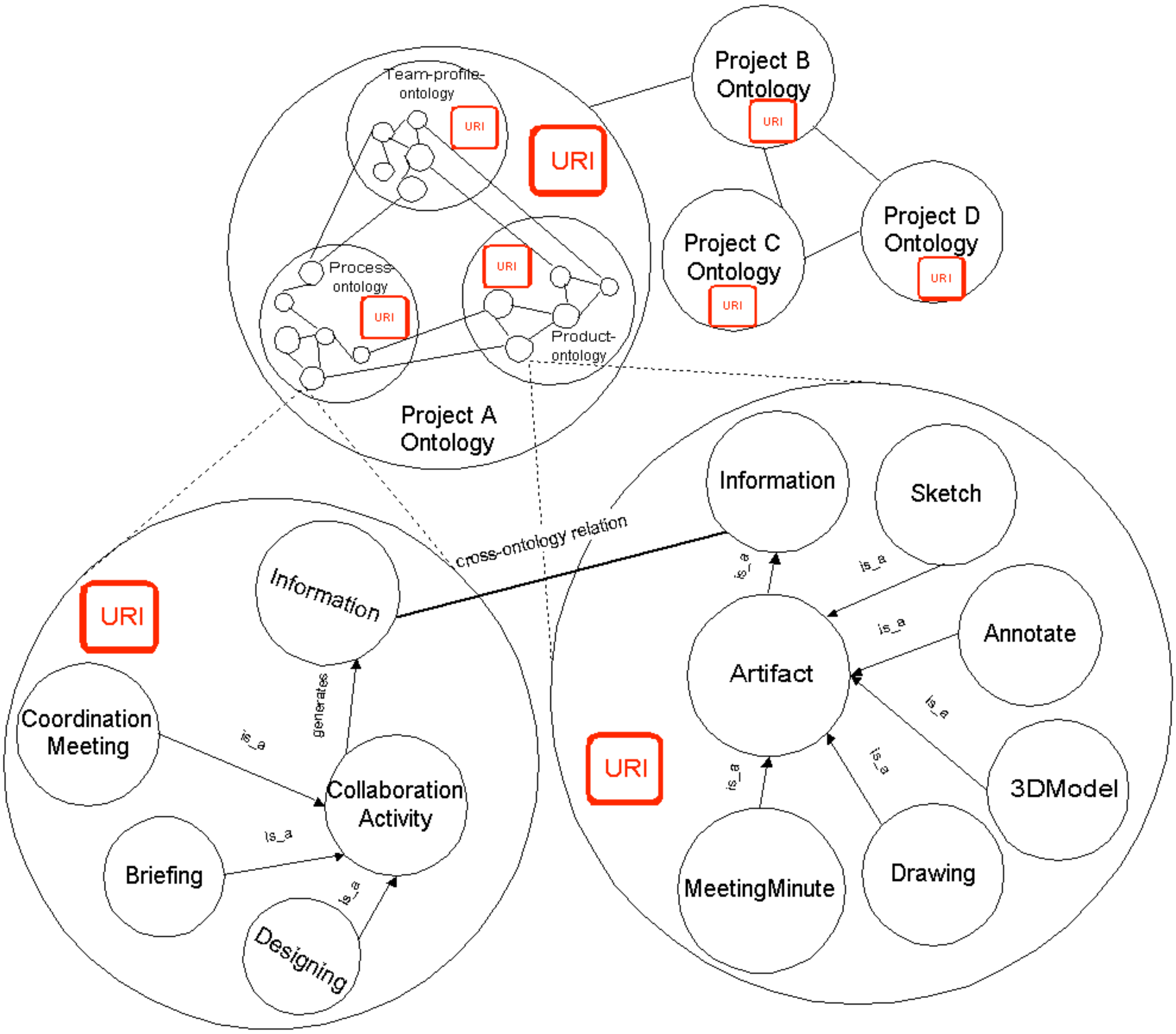

Figure 2: The use of ontology network as an approach to represent domain knowledge

Sesame (detail see http://sesame.aidministration.nl), an open source RDF (data and Schema) based repository and querying facility was used as the development base of the prototype system. RQL is the query language used in Sesame and therefore implemented in this prototype system as the means of accessing information in RDF data and schemas (detail see Broekstra & Kampman, 2001). A graphical user interface was developed for the prototype system to facilitate the input of query requests. SemTalk (Fillies, 2002), a graphical ontology modelling tool was used as the RDF(S) editor to facilitate the user in establishing RDFS based lightweight ontology (meta model) to expand the network of knowledge representations. The schematic diagram of the prototype system is illustrated in Figure 3. The compound of RDF and RDFS is denoted as RDF(S) in this article.

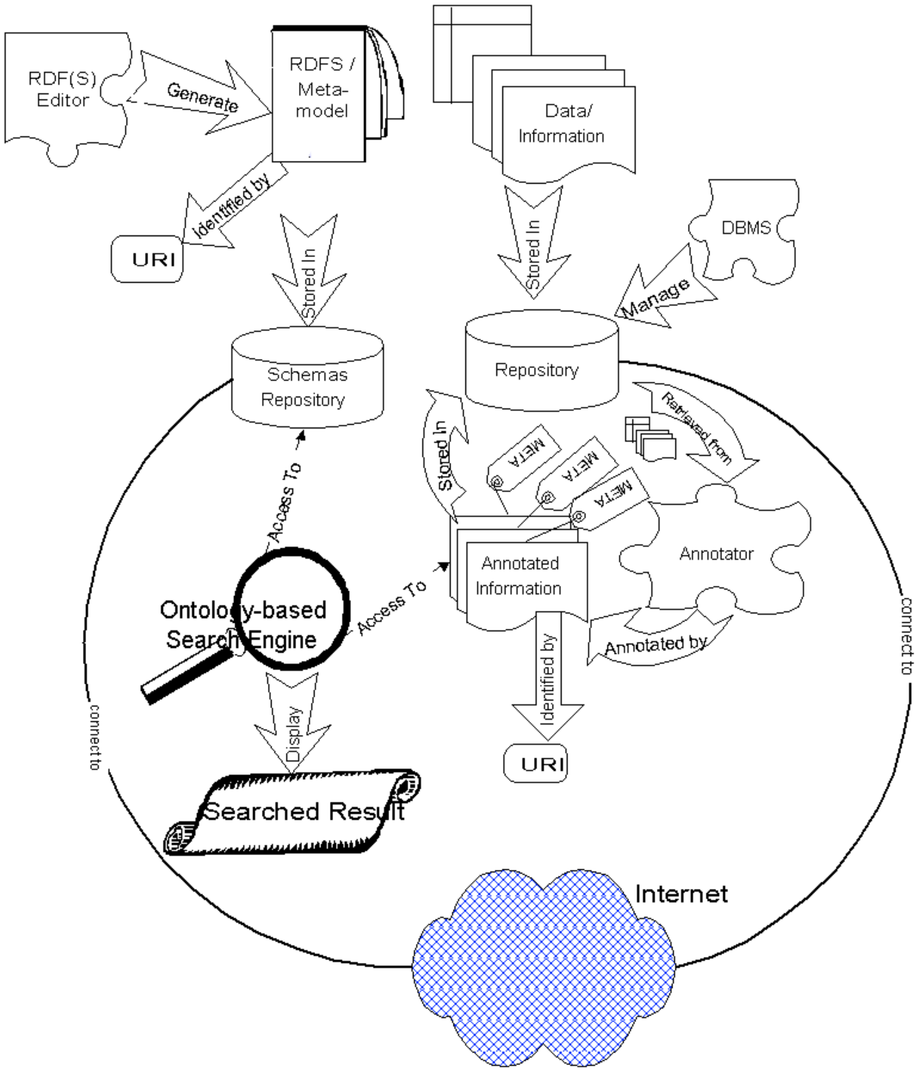

Figure 3: Schematic Diagram of the prototype Semantic Web based Knowledge Management system

Ontology (meta-model) generated with RDF(S) editor is stored with a specific URI in a physical container (repository). Existing information archived in another physical container is annotated with meta-tag by using an annotator. The annotated information specified with URI can be stored in the same repository as the one where the original information is stored. It can also be stored in a different repository. The annotated information can be stored separately from its corresponding ontology. The ontology-based search engine accesses the ontology and its corresponding annotated information based on queries requested by the human user. The search engine displays its searched result as lists of URIs. The searched result is accessible by the user when all of the related repositories are connected to the Internet.

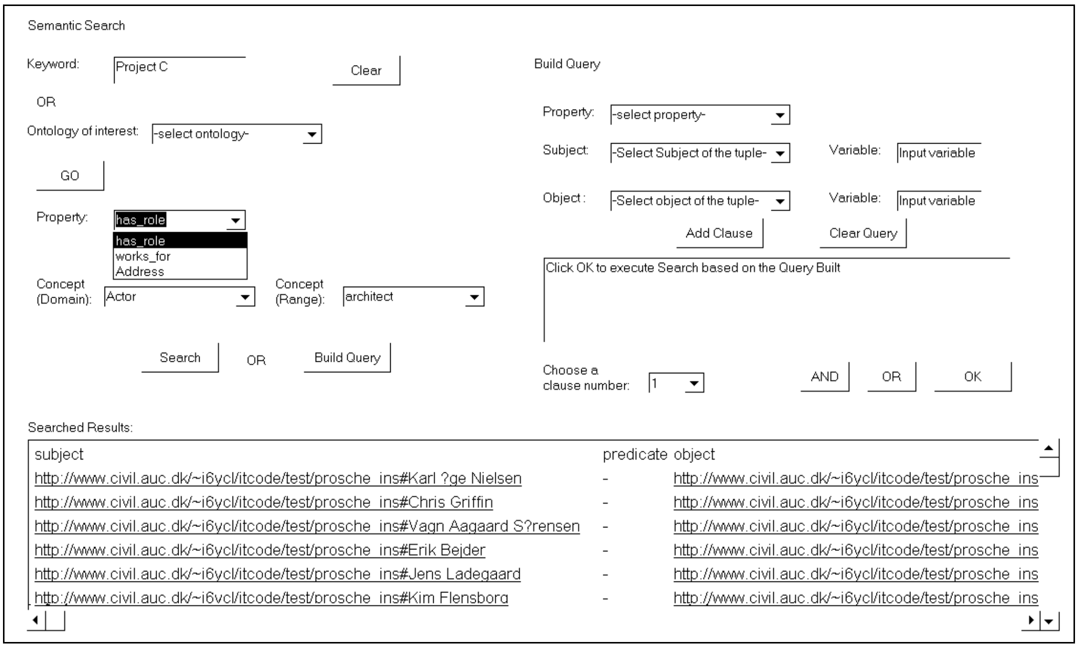

Figure 4: User Interface (UI) of the Semantic Search and the associated Searched Results. After “keyword” or “ontology” specification, the given “property” value further narrows down the search. Complex queries (upper right in Figure 4) can also be built. The searched results are displayed as lists of URIs.

5. Discussion

With respect to the dilemma of knowledge management that the building sector is facing, a lightweight ontology based prototype system was developed at its infancy stage in order to test the formulated hypothesis that a Semantic Web based knowledge management system is able to significantly extend the collaboration support amongst project stakeholders. To date, this early prototype system can merely support semantic search that is efficient in information retrieval. Evaluation of the basic function was undertaken based on the previously described examples of scenarios.

The semantic search function can be activated with simple queries consisting of a small number of search terms, which are linked to the predefined ontologies that are respectively accessible via unique URIs. A list of properties derived from the predefined ontology is available for the user to choose in order to provide an overview of the search scope (see Figure 4). Additionally, the users can select a concept (“Class” as defined in the RDF(S)) which is ontologically related to the chosen property. In other words, a RDF triple based search can be built by specifying the domain and range of the chosen property. As indicated in Figure 4, the semantic search of the triple *(Actor, has_role, architect)* was built to give access to the RDF(S) specific contents of the RDF triple store. The semantic search query would return the instances of the class “Actor” that matches the pattern of the stored RDF triples as its results. Another user interface is being developed in IT-CODE for composing more complex query, as shown at the upper right side of Figure 4. Very specific result can be expected from the complex query search when the user is able to explicitly define the search scope. The complex query handled by the RQL allows effective search through pattern matching along the path defined in the RDF triples based on their corresponding RDFS.

As demonstrated in the lower part of Figure 4, the searched result is displayed simultaneously with some ontologically related metadata conforming to the inherent structure derived from the underlying ontology. In other words, the RDF triples of the instances of search query were displayed based on the underlying structure of *subject*, *predicate* and *object*. Such a presentation mechanism provides the user with deeper understanding about the contextual belongings of the searched result. This can also avoid misunderstandings that arise from the use of different professional languages amongst the stakeholders. Listing the selectable properties and concepts (classes) is another alternative applied to overcome misunderstanding. Such lists are a means to summarise the structure of the selected ontology so that the users can justify search on the right path. Thus, the users can avoid spending excessive time in browsing irrelevant information compared to the apparent shortcomings of conventional keyword search.

The system is capable of handling query request to retrieve the electronic information of interest from a specific repository provided it is Internet accessible. The ontology network, see also Figure 2, is the basis of this system to integrate information that is distributed across Internet. Under the circumstances, it is no longer necessary for information to be stored in one centralised repository. A project specific ontology is created by the one who is assigned with this task or the one who is responsible for coordinating the project progress. The project relevant information can be annotated with an annotator system, which is lacking in this early prototype, with reference to the predefined ontology to create machine-readable metadata. The collection of ontologies and marked-up (annotated) information (or metadata) can be stored in a web server run by the organisation to which the involved stakeholder is affiliated. This strategy may eliminate the extra workload, either real or perceived, of having to use extra applications to run a project-oriented knowledge (information) base, such as the project web, and bridge the islands of information containers that existed amongst the groups of organisations that handle the same project.

At this stage, limitations as delineated in the following have been identified from this prototype system. The system was developed with the assumption that the building project stakeholders have good knowledge of ICT. They are assumed able to create ontology and metadata occasionally to update the semantic content (collections of ontologies and metadata) of the system after intensive training is given. The means of annotating the weakly structured information such as sketches and briefing notes is currently unavailable in the prototype system. The metadata used in the prototype system was created manually from the historical data of the case study with the RDF(S) editor. The capability of the prototype system in regard to identifying redundant information, which is commonly found in those weakly structured resources, has not been evaluated.

6. Anticipated Applications

IT-CODE (see Lai et al., 2002) is a conceptual system that aims at enhancing collaboration amongst key stakeholders in order to improve the efficiency and effectiveness of the early design process of a building project via the use of Semantic Web. Shared value built between project stakeholders supports the decision-making process, which is crucial particularly at the early design stage. Common workspace and information sources form the basis for conducting collaborative activities, and thus play a vital role in establishing shared values. The functionalities of the above-discussed Semantic Web based knowledge management system are apparently contributable to this goal. The developing prototype system provides a more user-friendly environment as all sorts of information can be annotated. Application of the IT-CODE with various appropriate ICT tools linked will enable the creation of semi-structured information such as sketches, client requirements in digital format. Meanwhile, IT-CODE provides a virtual meeting environment that is Internet accessible, and will allow the meeting context to be recorded and efficiently reusable to provide the users with knowledge of the decision intent and rationale. The knowledge management prototype system plays the role of managing semi-structured information that is neglected by most of the conventional archive mechanisms.

Early design, an inherently iterative process, produces more than one solution. These solutions are referred to and modified by various involved stakeholders numerous times during the design process. It is therefore necessary to keep track of the changing progress of these solutions, each of which has influence on one another, by revealing the implicit relationships between them. With its communication tools, content sharing tools and joint activity tools, IT-CODE is devoted to handling early alternative designs, as described in the above scenario, and to reduce the generation of non-treatable redundant information.

7. Future Research

This knowledge management prototype system will be developed and refined with respect to the identified limitations to attain the anticipated functionalities. In addition, further investigation on capturing the decision intent is essential to determine the level of detail at which design rationale and intent need to be captured. Application of the prototype system on a live project is another strand of future research to gather user response and capture user needs as the stimulant to trigger further improvement.

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