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ONTOLOGY BASED KNOWLEDGE RETRIEVAL IN CONSTRUCTION PROJECTS: FOCUSED ON THE CONSTRUCTION PROCESS

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ABSTRACT: Managing knowledge effectively is a critical factor for the competitive power of a company. There are efforts to use knowledge as an important resource in many industrial areas and likewise the interest in knowledge management is growing in the construction industry. Nevertheless, there are limitations in the current capture and reuse of knowledge in the construction industry owing to the unique characteristics of the knowledge created during the processes of projects. The knowledge produced during the processes of construction projects is project-oriented, experiential and context specific and due to these characteristics the reuse of knowledge is difficult. In this research, we focus on capturing and identifying the characteristics of construction knowledge and propose a method to apply these characteristics in developing an ontology based construction knowledge retrieval system to improve construction knowledge retrieval and enhance knowledge reuse.

Keywords: Knowledge Retrieval, Ontology, Construction Knowledge

1. INTRODUCTION

The construction industry is one of the information-intensive industries that have the potential to benefit from systematic management of knowledge. Effective knowledge management can reduce project time and cost, improve quality, and provide a major source of competitive advantage for the construction organizations [1]. Being a project-oriented industry most of the knowledge of the construction industry is generated in the processes of a project and managing this knowledge can help to prevent starting a similar project from scratch and not repeat similar mistakes made in the past projects. Also, managing this knowledge can serve as the basis for innovation and overall improvement [2]. These benefits and importance of knowledge management is increasingly recognized in the construction industry and many researches on this issue are being carried on [1].

Despite this growing awareness of the importance of knowledge management to the industry, there are limitations in the current capture and reuse of project knowledge [2]. The barrier to capture and reuse project knowledge is caused by the characteristics of the knowledge that they are project-oriented, context specific and experiential. Due to the nature that construction projects are unique, temporary, non-routine, and non-repetitive, the knowledge generated in projects are hard to be reused in new projects because the current retrieval of relevant knowledge is ineffective. The knowledge is closely tied to the person who created it and the context it was created, so even though construction companies successfully collect and store construction knowledge, the poor retrieval of knowledge makes it difficult to fully benefit from this valuable asset. Also, much knowledge during the construction phase of projects resides in individual's heads and is wasted at the end of projects as individuals move on to new projects.

To enhance the reuse of both explicit and tacit knowledge generated in construction projects, more effective way of retrieving the relevant knowledge to the right situation is needed. In this research, ontology based knowledge retrieval system is proposed for this purpose. Ontologies provide a framework for representing, sharing, and managing domain knowledge through a system of concept hierarchies (taxonomies), associative relations (to link concepts across hierarchies), and axioms that allows reasoning in a semantic way [3]. An ontology is the cornerstone of any effective collaborative KM system in a multifaceted domain.[4]

The basic structure for the ontology was developed as part of the LEAN System (Web-based Distributed Lean Construction Information System). The LEAN System is a blog based portal which aims to integrate and manage construction knowledge from different firms and projects. It consists of three types of blogs: corporate blog, project blog and personal blog. The ontology developed in this research will serve as a basis for effective knowledge retrieval from distributed knowledge sources in different blogs.

2. LITERATURE REVIEW

2.1 Ontology

Ontology originates from philosophical studies and has become an important component in information technology. There are many definitions for ontology and one of the best known is the definition by Thomas R.Gruber, "an explicit specification of a shared conceptualization" [8]. In other words, ontology is the idea of a concept that people have in their mind, expressed in a machine-readable manner.

Generally, ontology consists of concepts (or classes), properties, relationships, constraints, axioms and instances. A 'concept (or class)' is a unit that represents a thing that exists in the world. It can be something that can be sensed physically like 'truck', 'concrete' and it can also be something abstract like 'love', 'schedule', 'process'. 'Property' is the character and attribute inherent in a concept and 'relationship' shows how concepts are connected to other concepts. 'Constraint' is a rule or regulation about the 'property' and 'relationship' of a concept. 'Axiom' is a constraint that is always true and is the basis for reasoning. 'Instance' is also called as 'individual' and it is the most specific entity of a concept (or class).

2.2 Ontology in the Construction Domain

The research on application of ontology to the construction domain was first presented by the e-COGNOS project (COnsistent knowledGe management across prOjects and between enterpriSes in the construction domain; IST–2000-28671). Its aim was to develop an ontology-based web services system for management of construction knowledge [9].

The e-COGNOS ontology is developed using a variety of resources that are already developed in the construction sector and have the potential to become ontology, ranging from process and product models to specialized taxonomies. The concepts and relations are grounded on the IFC entities and are incorporated from existing classifications/taxonomies like UniClass, BS6100 and bsTaxonomy. 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).[9]

The e-COGNOS ontology captures the main entities throughout construction, as well as their attributes and interrelationships. Many further researches on the application of ontologies in construction are based on the e-COGNOS ontology. Using the basic model of the e-COGNOS ontology, other ontologies that have a more specific application like knowledge management in highway construction have been developed [10].

3. REASEARCH SCOPE & METHODOLOGY

No single ontology will be able to fully cover a domain nor will it satisfy the needs and preferences of each user

[5,6]. Therefore, it is important to set an explicit objective and scope for the application of the ontology. The ontology for this research is focused on representing the concepts of the construction phase of construction projects in the engineering perspective and the end-users will be construction project participants working on-site like construction manager and construction engineers. Moreover, the application of the ontology is focused on retrieving project knowledge.

Prior to the development of the ontology, the characteristics of knowledge created and used in construction projects are captured and the scenarios for the knowledge reuse are investigated. The basic structure of the construction ontology will be developed based on the characteristics and user scenarios of construction knowledge. Moreover, the system framework of ontology based construction knowledge retrieval system is suggested.

The most well known approaches for building ontology are Cyc methodology, Uschold and King's methodology (Uschold & King, 1995), TOVE methodology (Gruninger & Fox, 1995), METHONTOLOGY(Gomez-Perez et al. 1996), OnToKnowledge methodology(S.Staab et al. 2001). Although they have different approaches, they follow a typical procedure. Fig.1 shows the main stages for building ontology. The main stages for ontology development will be followed in this research.

- Specification: In this stage, the main goal and the scope of ontology is determined. What kind domain the ontology will represent and manage is specified in this stage. It states why the ontology is being build, what its intended uses are and who the end-users are. The characteristics and the user scenarios for the construction knowledge are identified in following section of this paper.
- Conceptualization: Based on the specification of ontology, appropriate concepts to represent the domain and to satisfy the use cases are captured and defined. For identifying the main concepts in the ontology, three strategies were proposed in the Uschold and King's methodology[7]: top-down approach, in which the most abstract concepts are identified first and then, specialized into more specific concepts; a bottom-up approach, in which the most specific concepts are identified first and then generalized into more abstract concept; and a middle-out approach, in which the most important concepts are identified first and then generalized and specialized into other concepts. The construction ontology is conceptualized by the middle-out approach as it puts emphasis on its application.
- Formalization: The conceptual model is transformed into a formal or semi-computable model. The concepts are formed into a taxonomy to show the hierarchical relations and moreover, the non-hierarchical relations are decided between concepts.
- Implementation: The formalized model is then implemented into a representation language which the system (machine) can understand. The W3C (World Wide Web Consortium) recommends the RDF and OWL as the ontology language.
- Validation: The ontology is validated by the use of competency questions. Competency questions are a set of questions to assure consistent categorization and modeling of ontologies. This technique was proposed by Gruninger & Fox (1994) and is widely regarded as one of the most suitable and effective means for ontology validation [4].

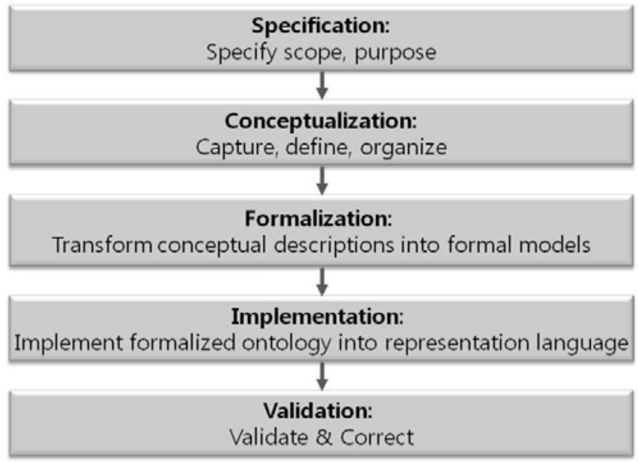

Fig. 1. Ontology development process

4. CONSTRUCTION KNOWLEDGE

Both explicit and tacit knowledge is generated during a construction project. Explicit knowledge is that which could be physically stored and made available to others. For the construction industry these include specifications, standard operating procedures, construction reports, best practice guides, textbooks, etc [1, 11]. Tacit knowledge is that which is stored in human's minds and is difficult to formalize and manage. Still, after or during a construction project, there are efforts to store tacit knowledge like know-how, lessons learned and construction cases into an explicit form such as construction reports and documents on a personal repository.

Despite the non-repetitive nature of the projects, knowledge and skills from one project might be transferred or applied to solve the problems of another one if relationships between existing solutions and problems can be established between them [12]. Therefore, capturing and representing the features that can be the criterion for determining the relevance of the situation of knowledge use and the context of previous knowledge is essential for the reuse of knowledge.

Most of the knowledge of the construction industry is generated in projects during the progress to deliver a custom-built facility [2]. Hence, to reuse the construction knowledge, the context of the knowledge should include in what project or process it was created or used. Showing the context of knowledge based on what kind of project it was generated, judgment whether the knowledge is appropriate and relevant for use in other projects can be made. In other words, a project participant can judge whether the knowledge was generated or used in a similar context. Showing in what process the knowledge was generated or used is also important. A project participant will be able to know what process the knowledge is related to and will be able to retrieve the knowledge at the appropriate stage of construction. Work environment and conditions are important features to represent context but considering all these features will make the retrieval of knowledge too specific and consequently, make it difficult to find the knowledge that fits all the context information.

The content of the knowledge is another aspect to be considered for the reuse. For a construction manager, the important concepts needed to represent the content of construction knowledge for reuse can be derived by investigating different parts of project management: Cost management, schedule management, quality management, safety management, procurement management, human resource management and etc. Although representing each managerial part with ontology is beyond the scope of this research, general concepts in the project such as resource, product and construction process can partially represent the knowledge. In cost management and procurement management, what resources are used is important in cost estimating. In schedule management, quality management and safety management, what kind of activity or process is progressed, in which process safety accidents happened and in which process the deficiency was discovered, can be an interest to a project participant. For a construction engineer, how the product was produced and what kind of resources was used in recent projects can be an interest.

Along with explicit knowledge, a lot of knowledge and skills based on experience resides in project participant's heads as tacit knowledge and are not shared after the completion of a project. Showing what kind of projects and what kind of knowledge the person created can help find the right person to get help will be a way to make use of tacit knowledge.

5. CONSTRUCTION ONTOLOGY FOR PROJECT KNOWLEDGE RETRIEVAL

The basic framework for the construction ontology is developed as to represent the context and content of construction knowledge. Considering the characteristics and usages of knowledge investigated in the previous section, five of main concepts are adopted from the e-COGNOS ontology and one is derived from the usage needs. The six main concepts (classes) of the construction ontology are 'Project', 'Actor', 'Process', 'Resource', 'Product' and 'Method'. Gruninger and others (1997) stated that the first five concepts are very common in most taxonomies [3]. The main concepts of the ontology will be used to represent the construction project which will be the basis of representing the context of construction knowledge. The instances and properties of 'Project' and 'Process' is to represent the context of the knowledge and the instances and properties of 'Actor', 'Resource', 'Method' are for representing the content of the knowledge. Also, the class 'Actor' plays an important role in forming a network between construction participants to share each other's experience and skills. Fig. 2 shows an abstract view on the main concepts of construction ontology: 'Actors' participate in a 'Project' to produce a 'Product' that is to be delivered. A 'Product' is produced through stages of different 'Processes' utilizing different methods and resources.

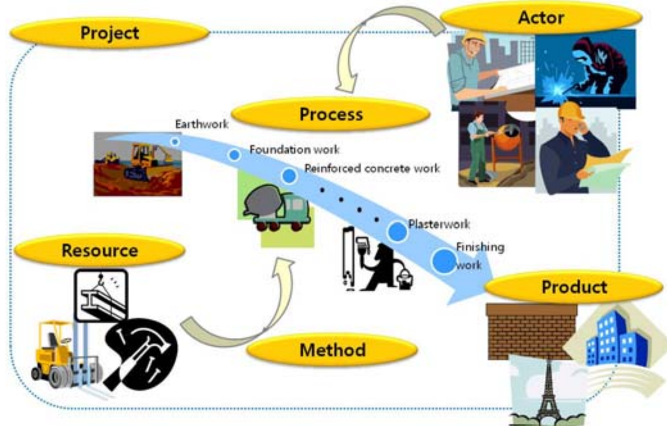

Fig. 2. Conceptualization of a Construction Project

The overview of the six main concepts is as follows.

- Actor: This class defines major participants in a construction project. It includes both 'Personnel' and 'Organization'. 'Personnel' is a subclass of 'Actor' that includes individuals participating in a construction project. 'Organization' is another subclass which includes construction companies, contractors, the government and etc. This class has position and role as its property. To share tacit knowledge among people, the instances of this class are the basis for forming a human network.
- Process: This class consists of administrative and engineering processes. In this research the ontology focuses on the field construction process of the engineering process. The 23 construction processes such as earthwork, concrete work and etc., compose this class. The processes are from the standard classification of construction works established by the Korean MLTM (Ministry of Land, Transport and Maritime Affairs).
- Resource: This class includes 'Material', 'Equipment', 'Labor' as its subclass. The subclass 'Labor' includes concepts and instances that also exist in the class 'Actor'. For example, a 'Mechanical Engineer' can be an 'Actor' who participates in a project and also can be a 'Resource' inputted into a process. The cognition of 'Mechanical Engineer' is different depending on what class the interpretation will be based on. Hence, two different interpretation of a concept is distinguished into different classes. This is one of the roles of an ontology, to represent the semantics of a concept.
- Method: This class represents techniques and mechanisms used to accomplish different 'Processes'. For example, 'Earth Anchor Method' is used in 'Earth work Process'. Unlike other classes, the instances of

this class is difficult to be developed because new techniques with new names appear frequently. Nevertheless, in the names of every 'Method', it is denoted with words like '~ method', '~ technique', so, will be able to be captured even though it is new.

- Product: The subclasses for this class are adopted from the e-COGNOS ontology which includes most of IFC concepts, a considerable number of concepts from BS6100 and benchmarks leading e-procurement standards such as the Common Procurement Vocabulary (CPV 2001)[3]. The subclasses of this class are 'Basic Products' (doors, wall, etc.), 'Construction Complex/Facility' (highway, factory, etc.), 'Material' (natural-soil, manufactured-concrete, etc.), 'Construction Aids' (scaffolds, cofferdams, etc.) and 'Management Products' (safety report, budget, etc.). In this research, the focus will be on 'Construction Complex' to be able to represent the final deliverable of a project.
- Project: This class is the major concept to represent the context of knowledge. The properties of this class are 'Contract Type', 'Delivery Type', and 'Delivery Method'. Instances of 'Contract Type' are such as fixed price and reimbursable cost, instances of 'Delivery Type' are such as design-build, turnkey and for 'Delivery Method' it is sequential delivery or fast track. What the deliverables (facility/building type) of a certain project is an important reference when searching for relevant knowledge. It is represented by the relation between 'Project' and the class 'Product'.

Retrieving knowledge based on what project it was generated or used will enhance the retrieval of relevant knowledge, so, relationships will be developed project-centered and other 5 classes will form a relation with 'Project'. In each class, instances will be included to be the base for ontology matching. The instances for each class are to be adopted from existing classifications, taxonomies and knowledge sources. Fig. 3 shows the relationship between the major concepts of the suggested construction ontology.

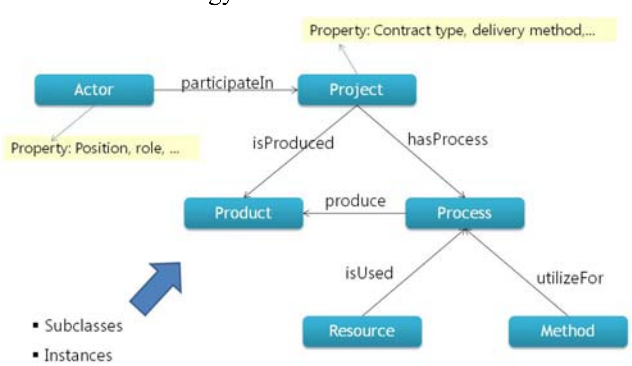

Fig. 3. Construction Ontology Framework

6. ONTOLOGY BASED CONSTRUCTION KNOWLEDGE RETRIEVAL SYSTEM

The knowledge retrieval system focuses on retrieving its knowledge on its content and context based on the developed ontology. The context of construction knowledge is represented by what project it was generated and used and by what classification the knowledge is categorized. Fig.4 shows the three ways of representing the context of knowledge in the proposed system. Fig.4(a) shows that context of a knowledge stored in a project blog is represented by the project metadata. Project metadata consists of the period of the project, supervisor of the project, properties of the project and etc. Fig.4(b) shows context of a knowledge in a personal blog can be also represented by the project metadata by inferring from what project ('Project) an person ('Actor') participated in. Fig4(c) shows that the classification based on construction process can be one perspective to represent the context of knowledge. A construction process is selected as the category of knowledge when uploading knowledge.

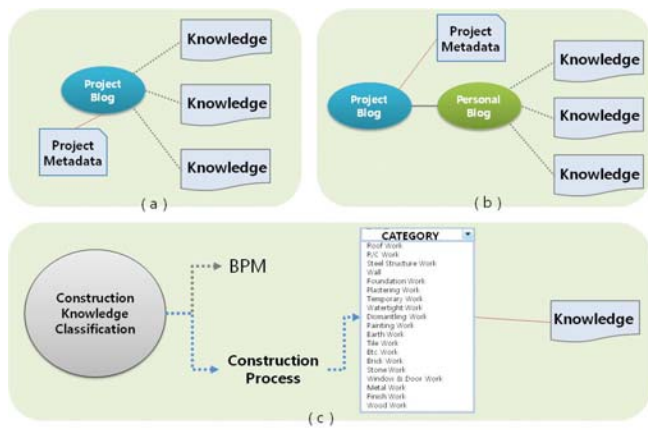

Fig. 4. Representing the Context of Construction knowledge

The content of knowledge is represented by features of the knowledge content. Features are keywords that frequently appear in the knowledge text. These keywords have a matching instance in the construction ontology and are recognized by the system as an instance rather than just a compound of letters. The semantic meaning is given to a word by the 'Semantic Annotator'. It is a component of the system which matches a word in the text to a concept/instance that is included in the construction ontology and denotes (tags) the class the word is included in.

The representation of a 'Project' is developed by the project basic information and the relationships with other classes. The basic information for the project is inputted in the start of a project and is analyzed to create the projects metadata. The knowledge stored in the project blog is analyzed to capture its features and these features forms the instances of other classes ('Actor', 'Product', 'Method', 'Resource') that is in relationship with the 'Project'. The instances of 'Process' of a project is obtained from a schedule management module. Fig.5

shows the architecture of the construction knowledge retrieval system.

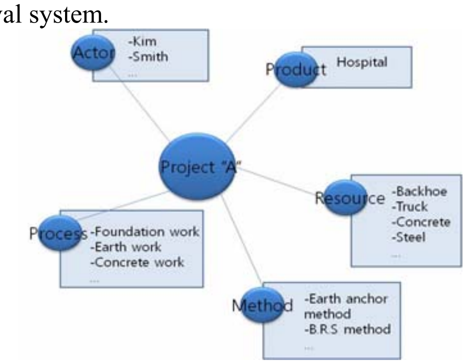

Fig. 5. Example of representing a project

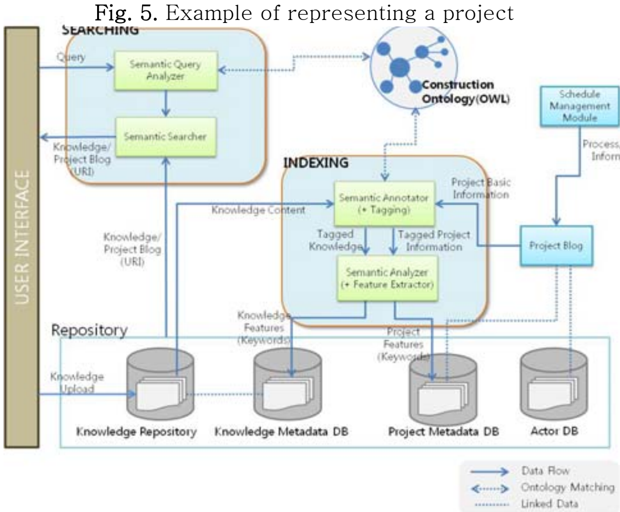

Fig. 6. Ontology based Knowledge Retrieval System Architecture

7. CONCLUSION

The ontology based retrieval system aims to provide enhancement in the construction knowledge reuse. Applying the ontology to the retrieval system will enable the system to express and understand the semantic meaning of a vocabulary. Expressing and understanding the semantic meaning of words, the system can provide a more relevant knowledge that fulfills the user's intension.

The framework for the ontology is developed to capture the context and content of construction knowledge. The concepts to capture the context and content are chosen by examining the characteristics and usage of construction knowledge. This way it will better suit the construction practitioners' needs in reusing knowledge.

The success of knowledge management is intimately related to the knowledge sharing culture and participants' attitude. Therefore, forming a knowledge sharing culture is essential prior to applying a new technology for knowledge management. Nevertheless, the proposed system can contribute partially to making a knowledge sharing culture by enhancing the reuse process of knowledge.

Further studies are needed in identifying the characteristics and usage of construction knowledge. Investigation on what knowledge the construction companies are using currently and what kind of knowledge is in demand. Through surveys and interviews with construction practitioners the important aspects of construction knowledge is to be derived. Moreover, research on the validation of the ontology developed and the system is required.

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