# TOWARD A TECHNOLOGY FOR CORPORATE MEMORIES IN CONSTRUCTION

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*ABSTRACT: The recognition that knowledge is one of an enterprise's most important assets, decisively influencing its competitiveness, has attracted interest in comprehensive approaches to the basis activities of Knowledge Management (KM) and corporate memories. During the design, construction and operation of any facility knowledge is gained and lessons are learned. Over time, organisations involved in the construction process have the opportunity to accumulate a plethora of knowledge, some of which is learned at great human or financial cost. However, this knowledge is not systematically incorporated into the construction process of subsequent projects. Few construction organisations have systems for systematically capturing, acquiring, converting and connecting that knowledge or have any interest in doing so (Newcombe 1999, Philips, 1996). Besides, the traditional methods of gathering and converting lessons learned during the project life cycle have enjoyed limited success in the construction industry (Kartam, 1996). KM systems help organisations create value by converting information and individually available knowledge into group or organisationally available knowledge. Artificial Intelligence techniques – knowledge base systems, case-based reasoning, rationale systems and ontologies - play an important role in building KM systems. This paper looks at the use knowledge management in the construction organisations. It addresses the use of artificial intelligence techniques with knowledge management techniques for building a corporate memory management system for construction enterprises. Finally it presents a framework to build a corporate memory management system in construction.*

*KEYWORDS: Artificial intelligence, knowledge management, corporate memories.*

## 1. INTRODUCTION

It is recognised by several authors (Frank et al., 1999; Abecker et al, 1998; O'Leary; 1998a; O'Leary; 1997) that knowledge is one of an organisation's most important assets, decisively influencing its competitiveness, has attracted interest of several researchers in comprehensive approaches to the basic activities of Knowledge Management (KM) and corporate memories.

The role and importance of knowledge as a key source of potential advantage for construction organisations have been addressed by several authors (Egbu et al., 1999; Kulunga et al., 1998; Winch, 1998; Quintas et al., 1997). However, our review of literature would suggest that few studies have been conducted in the areas of knowledge organisation and management which have taken a construction industry perspective. Yet, the design and construction processes involve the creation, use and sharing knowledge within people across teams, projects and organisations (Egbu, et al, 1999). Many processes involve the creation and consumption of massive amount of knowledge. Much of studies of the studies on KM have been carried out in other industries such as manufacturing, pharmaceuticals, chemical, financial sectors and the information technology sectors.

During the design, construction and operation of any facility knowledge is gained and lessons are learned. Over time, organisations involved in the construction process have the opportunity to accumulate a plethora of knowledge, some of which is learned at great human or financial cost. However, this knowledge is not systematically incorporated into the construction processes of subsequent projects. Few construction organisations have systems for systematically capturing, acquiring, converting and connecting that knowledge or have any interest in doing so (Newcombe 1999, Philips, 1996).

According to Wiig (1993) "knowledge consists of truths and beliefs, perspectives and concepts, judgements and expectations, methodologies and know-how. In this sense knowledge adds value to information by providing selectivity and judgement. Knowledge can also be considered as existing in a array of forms, such as symbolic, embodied, embrained, and encultured (Collins, 1995). Knowledge organisation and management is a process of capturing, converting and connecting knowledge from different sources and connecting people or knowledge with that knowledge, usually using advanced information technology (O´Leary, 1998a).

KM from a construction organisation perspective involves the implementation of knowledge in such way that it adds value to the organisation. With the increased use of Information Technology (TI) by construction organisations, much of the information is generated in digital forma. Moreover, there is a growing demand for exchanging construction information over computer networks electronically. Knowledge organisation and management systems help organisations create value by converting information and individually available knowledge into group or organisationally available knowledge. Artificial Intelligence (AI) techniques – such intelligent agents, knowledge bases systems, case-based reasoning, rationale systems and ontologies- provide technology and tools to meet the growing demand for corporate-wide knowledge management systems.

This paper specifically reports the initial findings of a wider project aimed at to develop an AI corporate-wide memory for supporting knowledge intensive tasks inherent to a construction organisation. It addresses the use of artificial intelligence techniques with knowledge management techniques for building a corporate memory management system for construction enterprises. Finally it presents a framework to build a corporate memory management system in construction

## 2. RESEARCH METHODOLOGY

The objectives of the research were met through an intensive literature review, a modelling framework that reflects a convergence of ontological analysis approaches (Chandrasekaran et al. 1999; Fernández et al., 1997) and the Client Centred Approach (CCA) method (Watson et al. 1992).

The literature review provides the background on studies that have been conducted in the areas of knowledge organisation and management, AI in knowledge organisation and management, specifically, knowledge bases and ontologies.

The ontological analysis clarifies the structure of the ontologies of the domain, and enables knowledge converting and sharing. The ontologies form the heart of the organisational memory management system. The CCA method supports the implementation of the organisational memory through several phases and enables the involvement of all stakeholders in its development process.

## 3. THE ROLE OF THE CORPORATE MEMORY

The recognition that knowledge is one of an organisation's most important assets has attracted interest in comprehensive approaches to the basic activities of KM such as: *identification*, *acquisition*, *converting*, *connecting*, *use*, and *preservation* of the organisation's knowledge (Abecker et al., 1998). Therefore, there is an increasingly interest in the capitalisation of knowledge (that is both theoretical knowledge and practical know-how) of individuals, groups of individuals of an organisation (Frank, 1999; Dieng et al. 1998). The coherent integration of this dispersed knowledge in an organisation is called *corporate memory*. Organisations use KM to create valuable knowledge – structured around a corporate memory- from knowledge dispersed by different sources in the organisation (O'Leary, 1997, 1998a). Therefore, KM help organisations create active corporate-wide memory in four ways:

1. By acquiring and converting knowledge individually available into group or corporately available knowledge
2. By connecting people or knowledge to organisationally available knowledge
3. By providing the necessary knowledge whenever it is needed by knowledge-based applications
4. By maintaining and preserving corporate-wide knowledge.

Traditionally, organisations have addressed KM from either a management or a technological point of view. A number researchers in KM argue that effective corporate memory requires a hybrid solution, one that involves people and technology, to create valuable information from knowledge dispersed in different sources (Abecker et al., 1998; O'Leary, 1998a; Davenport, 1996).

To implement KM systems in a construction organisation to capture and make an effective use of knowledge and lessons learned from construction projects we need a framework built using both approaches: management and technological. At the core of this framework is a *corporate memory* shown in figure 1 (after Abecker et al., 1998). Arranged around such and the corporate memory, KM systems actively provide the user (individuals) working on knowledge-intensive construction tasks with all the information necessary for fulfilling his tasks. The central services of the organisational memory in figure 1 are: to provide necessary knowledge whenever it is needed; and to create valuable information.

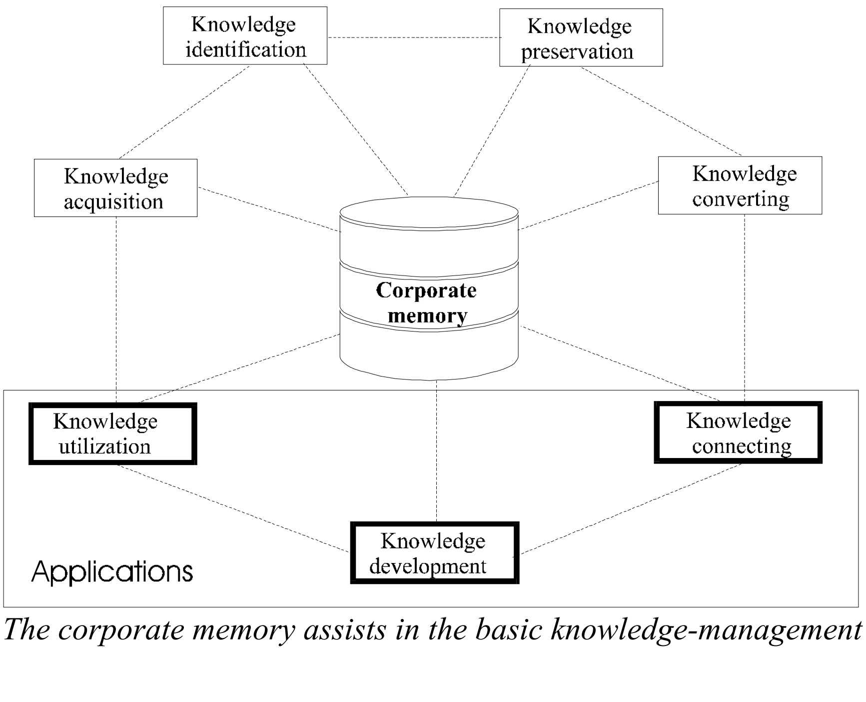


*Figure 1: The corporate memory assists in the basic knowledge-management activities*

For a corporate memory to be effective, applications for knowledge intensive tasks must receive relevant knowledge at the right time. Relevance of knowledge is defined here with respect to its use. Consequently, actively providing knowledge in a organisational model is primarily oriented according to a task model in addition to an user model. The biggest profit from support by an organisational memory will like come in knowledge-intensive tasks that area complex, difficult, and important by nature such as planning, budgeting, analysis, procurement, design, etc. Such knowledge-intensive tasks deal with the acquisition, conversion, creation, packing, and application of knowledge and can be supported assisted by a corporate memory within a learning organisation.

## 4. ARTIFICIAL INTELLIGENCE DEVELOPMENTS IN KNOWLEDGE ORGANISATION AND MANGEMENT

There are many similarities between AI and Knowledge Management (O´Leary, 1998b). For example knowledge-management system employ knowledge bases but for both human and machine consumption. A knowledge-based system also depends on ontologies to facilitate communication between multiple users and links between multiples knowledge-based systems (Chandrasekaran et al., 1999; Abecker, 1998).

Knowledge-based systems are a big consumer of knowledge to solve a variety of problems. In turn, knowledge bases rely on ontologies for specification of view and structure. Ontologies provide some structure for development of knowledge bases as well a basis for generating views of knowledge bases. AI techniques are being used to support knowledge management activities within an organisation. Consequently AI provides technology to design and implement corporate-wide knowledge management systems that are more than an information system and with capability to create valuable information. Table 1 summarises the full range of AI and KM techniques that have potential to support a corporate-wide knowledge management system.

*Table 1: AI techniques for KM activities*

| Knowledge source | KM activities | KM techniques | AI techniques |
|---|---|---|---|
| Individuals and groups<br>Data<br>Text | *Knowledge converting* | Knowledge harvesting<br>Knowledge discovery | Knowledge engineering tools Ontologies, Linguistic analysis, rationale systems. Ontologies, Intelligent agents, multiagent systems. |
| | *Knowledge development* | Knowledge bases | Knowledge-based systems, case-based reasoning, model-based reasoning, ontologies |
| | *Knowledge connecting* | Knowledge bases<br>Search engines<br>Information retrieval | Intelligent user-interfaces, agent technology, case-based reasoning. |
| | *Knowledge utilisation* | Intranets<br>Knowledge bases | Intelligent user-interfaces, agent technology, |
| | Knowledge preservation | Large knowledge bases | Distributed knowledge-based expert systems, case-based reasoning |

## 5. WHY ARE ONTOLOGIES IMPORTANT?

Every knowledge-based model is committed to some conceptualisation, implicitly or explicitly. An explicit specification of this conceptualisation is called ontology (Gruber, 1993). Ontologies capture the intrinsic conceptual structure of the domain. In addition, ontologies enable knowledge reuse and sharing about the domain factual knowledge, reasoning strategies and problem solving methods across different applications (Chandrasekaran et al., 1999). Interest in ontologies has grown as AI researchers and system developers have become aware in reusing and sharing knowledge across several knowledge management applications (Willian and Tate, 1999; Chandrasekaran et al., 1999; Valente et al., 1999; Abecker, 1998; Benjamins and Fensel, 1998; Noy and Hafner, 1997; Lenat, 1995; Fox et al., 1993). Formally, an ontology consists of terms, their definitions, and axioms relating them (Gruber, 1993).Although differences exists in ontology design, general agreement exists between ontologies on many issues: there are number of general classes of concepts; there are objects in the world; objects have properties or attributes that can take values; objects can exist in various relations with each other; properties and relations can change over time; there are events that occur at different time instants; there are processes in which objects participate and that can occur over time; objects have parts; the world and its objects can be in different states. There are a number of engineering frameworks for constructing ontologies. Table 2 lists some of these frameworks.

*Table 2: Engineering frameworks for constructing ontologies*

| Project Name | Description | Purpose |
|---|---|---|
| Loom (McGregor, 1991) | Is a knowledge representation language. Loom is based on a semantic network approach to knowledge representation | It provide definition of concepts with roles or slots that can specify the concept's attributes |
| KIF knowledge Interchange Format) (Genesereth and Fikes, 1992). | Is a language for defining ontologies. KIF has declarative semantics, and it is based on first-order predicate calculus. | It provides for definition of objects, functions and relations. It provides for the representation of metaknowledge and allows for the representation of nonmonotonic reasoning rules |
| Ontolingua (Gruber, 1993) | Is a language for analysing, translating and constructing ontologies. Ontolingua is based on the frame ontology. Consequently, Ontolingua constructs for frames, slots, slot values and facets, can be built on top of KIF elements | It provides definition for portable ontologies |
| CYC (Lenat, 1995) | CYC contains more than 10,000 concept types used in the rules and facts encoded in the knowledge base. At the top of the hierarchy of CYC is the Thing concept which does not have any properties of its own. Thing concept has the subcategories individual object , intangible, and represented thing | It provides definition for general ontologies or top level ontologies |
| Sowa (Sowa 1997) | Sowa uses philosophical motivation as the basis for ontology categorisation. The Sowa's root T has the subcategories concrete, process, object, and abstract | It provides definition for general ontologies |
| Generalised Upper Model (GUM) (Bateman et al., 1994) | GUM is a general task and domain independent linguistically motivated ontology. GUM um-thing has the subcategories configuration, element, and sequence | It provides definition for general ontologies |
| Wordnet (Miller, 1990) | Wordnet is a manually constructed lexical reference system. Lexical objects in Wordnet are organised semantically. Its central object is synset, a set of synonyms | It provides definition for general ontologies |

| | | |
|---|---|---|
| CommKADS(Schreiber et al., 1994) | CommKADS is methodology for modelling domain knowledge | It provides a framework for modelling domain knowledge |
| Methontology (Fernández et. al. 1997) | Methontology is a framework for specifying ontologies at knowledge level. It includes identification of the ontology, a life cycle and the methodology itself | It provides guidelines for specifying ontologies at the knowledge-level |
| Ontology Development Environment (ODE) (López et al., 1999) | ODE goal is to support the ontologist throughout ontology development process. It automatically generates the code in Ontolingua. | It enables ontology construction |

## 6. THE PROPOSED CORPORATE MEMORY FRAMEWORK

The construction of a corporate memory management system requires abilities to manage disparate knowledge and know-how, and heterogeneous viewpoints, make this knowledge accessible to the adequate professionals, and store this knowledge in electronic documents, knowledge-bases or case bases. The central service of such corporate memory is: providing and sharing necessary knowledge whenever it is required by construction tasks. For this, the corporate memory realises an active knowledge dissemination and usage approach that automatically provides knowledge useful for solving the task at hand. We propose a three-level framework as sketched in figure 2, which points out the main issues to be addressed when building a corporate memory management system. These levels include: *resource level; knowledge level;* and *application level*.

Our approach models and executes processes and tasks on the application level. When a knowledge user recognises an information need within the actual flow a query to the organisational memory must be derived. In the opposite way, the corporate memory can also store new information created within a given task.

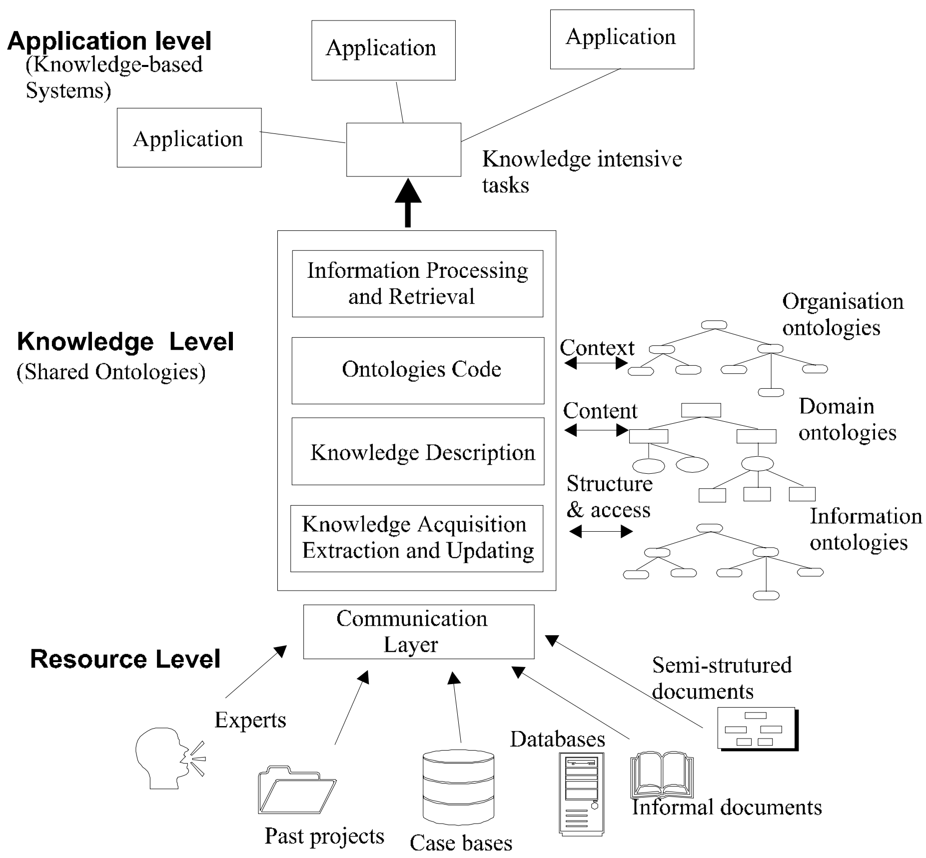


*Figure 2. A corporate memory framework*

Because a corporate memory relies substantially on existing information and knowledge sources, the *resource level* is characterised by a variety of sources, heterogeneous with respect to several dimensions concerning form and content properties. The corporate memory performs mapping from the application-specific information needs to these heterogeneous resource level sources. Thus, the resource level comprises manifold information and knowledge sources, ranging from machine-readable formal representation to human-readable informal representation. The *knowledge level* comprises the several implemented ontologies an enables a uniform, intelligent access to a diversity of resource level sources. The existence of this knowledge-rich information level allows us to incorporate all legacy information systems without modification.

Ontologies in the knowledge level form the heart of our framework for a corporate memory for construction organisations. Our goals for developing the ontologies within the proposed framework included:

- facilitate interoperation and communication between applications supported by the corporate memory;
- promote knowledge sharing between applications –in particular, integrate our knowledge acquisition and modelling efforts; and
- create a repository for domain knowledge, problem solving knowledge, and general knowledge.

The knowledge level comprises three kinds of ontologies: the information ontology; the domain ontology; and the organisation ontology. Essentially the information ontology comprises all aspects of information and knowledge sources that are not content specific. It also provides links into the domain ontology used for content description, and it provides links into the organisation ontology used to describe the creation context and the intended utilisation context of domain knowledge. The domain ontology is used for modelling the content of information sources such as: case bases, databases, text documents and formal knowledge. The organisation ontology is expressed in terms of organisational structure, process models, problem-solving strategies, best practices, lessons learned, and process rules.

The *application level* links the information model and the concrete application situation.

## 7. IMPLEMENTATION

Knowledge is data (also referred to as facts) and the organisation of facts, including the relationships between facts. A set of facts and relationships is called knowledge base. Since knowledge is often hierarchical in nature, knowledge modelling and representation can be partially expressed as a set of class hierarchies in today's object oriented programming paradigms Many relation between facts including rules and constraints can be modelled as methods using object oriented paradigm.

Object technology has been widely accepted as a paradigm that will resolve many of the problems inherent in information systems development and management (Chandra et al. 2000). This is consistent with the Object Management Group's (OMG) vision of the future: a common standard for objects enabling the development of purchasable, sharable, and reusable information assets existing in a world-wide network of interoperable inter-organisational information systems. The object paradigm is powerful in four areas: software and data organisation; systems analysis and modelling; information resource management, and information sharing. Taking into account these features of the object paradigm, Allegro CL, Common Lisp Object System (CLOS) and Allegro ORB Link from Franz Inc. were chosen as the programming environment for developing a prototype of a corporate memory system. Allegro CL and CLOS provides a very powerful programming environment that allows developers to design and implement reusable and shareable ontologies and dynamic knowledge based systems. Allegro CL incorporates the Dynamic Object technology, which enables a developer to model fast-changing situations found in construction organisations. One of the key strengths of CLOS is its extensibility, enabling the language to be "custom-tailored" to the domain specific application areas. Allegro ORB Link provide tools for invoking methods on objects on remote machines, access common CORBA services, access remote databases and COM objects and interoperate with other commercial databases management systems.

As shown in figure 3, the implementation of the corporate framework uses a multi-tier client server infrastructure to demonstrate the integration between different data/knowledge sources and knowledge based system though implemented ontologies. The layers are connected via the corporate Local Area Network (LAN), intranet or the internet.

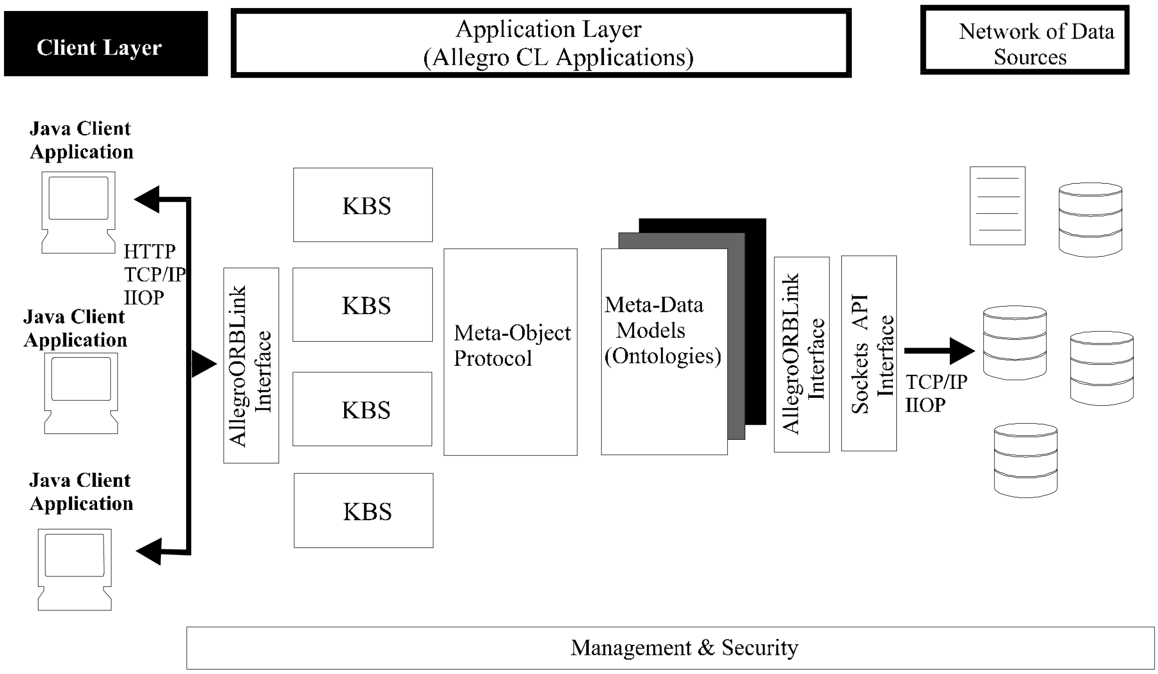


*Figure 3. Overview of the corporate memory infrastructure*

This architecture consists of a network data layer, an application server layer and a "thin" client layer. The network data layer contains corporate information sources. At the intermediate is the application layer. The application layer includes:

- The **meta-data models** describe the domain ontologies, the organisation ontologies and the information ontologies using CLOS language.
- The **meta-object protocol** in Common Lisp which contains a set of default rules about how the CLOS object ontologies work: how methods are added, how classes are inherit from superclasses, etc.
- Several **Knowledge-Based Systems** (KBSs) such as software agents, expert systems, intelligent decision support systems. This systems form the core of mainstream corporate applications.

- The **communication interfaces** between the application layer and the network data layer and between the application layer and client layer. These interfaces uses the capabilities of Allegro ORBLink and Allegro CL over the network protocols.

The client layer consists of either a desktop PC or net-PC browser. The users can access the corporate memory through a Java application which can be accessed by any common Web browser.

The implementation of system is a staged process measured by the deliverables produced at each stage. The ontology development life cycle follows the Methontology framework (Fernández, et al. 1997). It consists of three stages: the *specification* of the ontologies; the *conceptualisation*, which organises and structure the corporate information; and the *implementation*, which implements the ontologies into meta-data models using CLOS language.

## 8. CONCLUSIONS

The need for enterprise-wide knowledge management brings with it a number of challenges for construction IT researchers. Knowledge it is recognised as one of the enterprise's most important assets. However, few studies have been conducted in the areas of knowledge management with a construction industry perspective.

This paper has set out a framework of an ongoing- research aimed to implement an AI-based corporate memory system to support construction knowledge intensive tasks. AI provides essential enabling techniques for components of the system. We found that developing a large corporate memory for multiple applications can be a painful process, and many proposed techniques do not work as easily in practice as hoped. Within the limits of this paper, an multi-tier architecture to implement the framework using object technology was presented.

The framework and the architecture discussed in this paper is an on-going project. It takes advantage of the related emerging technologies, including ontologies, knowledge management, dynamic objects and information agents. The main contribution of this paper is the use of technology to convert valuable knowledge available from corporate information resources and connecting this knowledge to the corporate users. Much work remains in order to obtain a finished infrastructure

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