KNOWLEDGE MANAGEMENT FOR THE CONSTRUCTION INDUSTRY: THE E-COGNOS PROJECT

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SUMMARY*: The paper focuses upon the contribution which adequate use of the latest development in Information and Communication Technologies can make to the enhancement, development and improvement of professional expertise in the Construction domain. The paper is based on the e-COGNOS project, which aims at specifying and developing an open model-based infrastructure and a set of tools that promote consistent knowledge management within collaborative construction environments. The specified solution emerged from a comprehensive analysis of the business and information / knowledge management practices of the project end-users, and makes use of a Construction specific ontology that is used as a basis for specifying adaptive mechanisms that can organise documents according to their contents and interdependencies, while maintaining their overall consistency. The e-Cognos web-based infrastructure will include services, which allow the creation, capture, indexing, retrieval and dissemination of knowledge. It also promotes the integration of third-party services, including proprietary tools. The e-COGNOS approach will be tested and evaluated through a series of field trials. This will be followed by the delivery of business recommendations regarding the deployment of e-COGNOS in the construction sector. The research is ongoing and supported by the European Commission under the IST programme – Key Action II.*

KEYWORDS*: knowledge management, construction industry, ontology, web services*

1. INTRODUCTION

It is the view of the e-COGNOS consortium that the European construction industry is characterised by some unique working practices. Foremost among these is the way that the Design and Construction process is fragmented, involving short-term partnering between actors from a variety of disciplines, sitting at different locations, with varying levels of IT support for their individual business processes. Similarly, the resulting output from these processes is likely to be a one-of-a-kind product.

Over the last decade, construction companies have invested heavily in the improvement of their business processes and new forms of innovative project management, supported by IT, appeared as a response to the ever-growing pressure from clients to deliver high quality facilities on time and on budget. As a consequence of the construction domain becoming highly information intensive, a new activity emerged from the process of managing projects and established itself as a discipline in its own right: that is the one of information and 'Knowledge Management'.

Organisations and individuals participating in a project bring their own unique skills and resources, which may include proprietary and commercial applications, knowledge and data. Despite the interest and the effort put into

knowledge management by many leading companies, the discipline is still in its infancy. Many practitioners and researchers have acknowledged the limitations of current approaches to managing the information and knowledge relating to and arising from a project (Rezgui, 2001). Among the key reasons for these limitations are:

- Much construction knowledge, by necessity, resides in the minds of the individuals working within the domain.
- The intent behind decisions is often not recorded or documented. It requires complex processes to track and record the thousands of ad-hoc messages, phone calls, memos, and conversations that comprise much project-related information.
- People responsible for collecting and archiving project data may not necessarily understand the specific needs of actors who will use it, such as the actors involved in the maintenance of the building(s).
- The data is usually not managed while it is created but instead it is captured and archived at the end of the construction stage. People who have knowledge about the project are likely to have left for another project by this time - their input is not captured.
- Lessons learned are not organised well and buried in details. It is difficult to compile and disseminate useful knowledge to other projects.
- Many companies maintain historical reports of their projects. Since people always move from one company to another, it is difficult to reach the original report authors who understand the hidden meaning of historical project data. This historical data should include a rich representation of data context, so that it can be used with minimum (or no) consultation.
- New approaches to the management of knowledge within and between firms imply major changes in individual roles and organisational processes. While the potential gains are desired, the necessary changes are resisted.

Knowledge in the construction domain can be classified into the three following categories:

- Domain knowledge: this forms the overall information context. It includes administrative information (e.g. zoning regulations, planning permission), standards, technical rules, product databases, etc. This information is, in principle, available to all companies, and is partly stored in electronic databases.
- Organisational knowledge: this is company specific, and is the intellectual capital of the firm. It resides both formally in company records and informally through the skilled processes of the firm. It also comprises knowledge about the personal skills, project experience of the employees and cross-organisational knowledge. The latter covers knowledge involved in business relationships with other partners, including clients, architects, engineering companies, and contractors.
- Project knowledge: this is the potential for usable knowledge and is at the source of much of the knowledge identified above. It is both knowledge each company has about the project and the knowledge that is created by the interaction between firms. It is not held in a form that promotes re-use (e.g. solutions to technical problems, or in avoiding repeated mistakes), thus companies and partnerships are generally unable to capitalise on this potential for creating knowledge. It includes both project records and the, recorded and unrecorded, memory of processes, problems and solutions.

These three categories - referred to as information layers in the paper, are obviously strongly inter-linked, in that any amendment introduced to one layer is very likely to have a critical impact on the others. In recent years, with the emergence of the Internet, many initiatives have resulted in the proliferation of information portal sites. The latter constitute a storefront with customers, clients, partners, suppliers and contractors, enabling actors to conduct their business over the Web. In addition, several European countries have developed web-based implementations of their regulations that are now available online. However, in the Construction sector, all these efforts towards KM have been undertaken by large enterprises for their internal needs, leading to many proprietary solutions. There is a need to supply the industry, including SME's, with a generic, modular and open

solution for KM that addresses the knowledge requirements of construction end-users while supporting their existing practices and taking into account the contractual, legal, IPR (Intellectual Property Rights), security, and confidentiality constraints. This is the complex problem situation that the e-COGNOS project aims to address.

2. THE E-COGNOS PROJECT

The overall aim of e-COGNOS (e-Cognos, 2000) is to specify, develop, and deploy an innovative open model-based infrastructure and a set of tools that promote effective and consistent KM (including capturing, organising, retrieving and disseminating) within collaborative construction environments. The detailed objectives of the project are listed hereafter:

- Understand and detail the specificity of KM activities requirements of European construction companies, as well as the organisational (including human resources management), contractual and legal aspects impacting on KM.
- Understand the semantics within and across heterogeneous construction documents as well as their complex interdependencies leading onto the development of model-based adaptive mechanisms that can organise documents ranging from unstructured (black-box) to highly structured (e.g. XML) ones according to their contents and interdependencies. This should rely on a high-level ontology of the construction domain to serve as a basis for knowledge indexing and retrieval.
- Specify a Web-based infrastructure, including Internet-based services (packaged in the form of an e-COGNOS API), allowing to create, classify, index, retrieve, and disseminate knowledge in a secure, tracked and managed environment which accommodates the existing complex information and knowledge interdependencies, and recognises intellectual property rights and confidentiality issues. This infrastructure will also enable user profiling.
- Implement and deploy the proposed KM infrastructure. This will include a set of identified proprietary, commercial, and national regulatory tools used across the three knowledge layers. It is anticipated that the e-COGNOS infrastructure will draw on the results of previous IST funded projects such as OSMOS, when specifying generic core services and integration components.
- Evaluate and validate the system in use within the construction domain, and assess the risks and benefits of adopting the proposed approach by implementing field trials.
- Set up three e-COGNOS Internet-based KM service prototypes for the purpose of the project, and ensure their take-up, as commercial offers, after the completion of the project.

A major e-COGNOS objective is the ability to deploy a flexible infrastructure allowing construction organisations to assimilate more efficiently and effectively large volumes of information, ensuring timeliness, relevance, accuracy, and completeness.

3. THE E-COGNOS METHODOLOGY

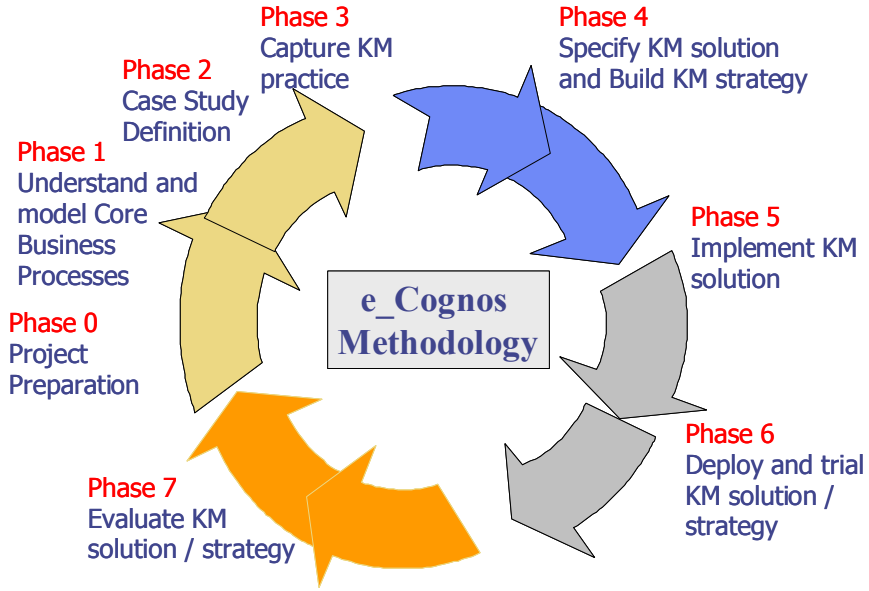

FIG. 1: The e-COGNOS methodology

Several methodologies have been developed to help formalise knowledge held by experts, technicians or project teams. Some of these target capitalisation of experience feedback (e.g. Rex), with the objective to reduce repetition of errors or dysfunction. Other methodologies (e.g. MKSM, CommonKADS) are more dedicated to the modelling of the enterprise itself, considered as a knowledge system. They aim at improving decision-making and draw up a map of corporate knowledge, and can lead to a strategic analysis, which takes into account critical knowledge, inefficiencies, risks, prospective management of skills and jobs. Finally, some methodologies (e.g. CEM) are more specifically intended to improve expression of tacit or implicit requirements in terms of knowledge management through interviews. The approach proposed by the consortium uses elements of Checkland's "Soft Systems Methodology" (SSM), and is fundamentally a cyclic approach, as detailed below. Each phase is described in more detail in the following sections.

Phase 0 aims to prepare the prospective e-Cognos user organisation for the knowledge management project. Many organisations may have had poor experiences with previous initiatives, which can lead to management and employee resistance to both the implementation and use of the system. Therefore, this stage is crucial to the potential success of the project, as it aims to build an initial understanding and commitment to the KM initiative. The key objectives of this stage may be summarised as:

- Build management understanding and commitment to undertake and pursue KM.
- Introduce and explain project to company staff: brochures, posters, briefing sessions.
- Assess risks related to project, and find out about company past initiatives (both successful and unsuccessful): KM, BPR, etc.
- Capture success and / or failure factors.

Phase 1 aims to model the core "high-level" business processes of each participant. This must be completed as either a new exercise, or alternatively organisations may have taken steps to model at least a portion of their core business processes as a part of a previous initiative, such as business Process Reengineering (BPR) – this can be often used as the starting point for an IDEF0 model (the proven process activity modelling method adopted by the consortium). The key objectives of this stage may be summarised as:

- Understand current company strategy: In what direction the company is going – what are their likely current / future strategic knowledge requirements?

- Understand the structure of the organization: Division of the work, the tasks, and the responsibilities both horizontally and vertically.
- Understand the culture of the organization: Values, norms and views shared by employees. These may be expressed in the form of Symbols, Rituals, Myths, Stories, Anecdotes, legends, so-called heroes.
- Understand the current Systems: Rules, Procedures, Guidelines, Software / Hardware systems in use.

The above analysis should be facilitated through the use of internal consultants (with support from academic and research institutions). Internal consultants will be less likely to encounter resistance and will be more respected by employees. This will help secure ownership of the KM process, which should help to ensure management support. The principles of Action Research (Responsiveness, Cyclic, Participative, Qualitative, Reflective) can be used during this analysis and should help to reveal past problems in creating and sharing knowledge within the organization. Similarly, reactions from employees can uncover cultural aspects of the organization, which may assist or hinder any KM strategy.

Phase 2 makes use of a case study that will help to highlight and refine the specific knowledge management requirements of the organization. This will centre on a specific process or business unit of the organization, which should be selected and analysed by first identifying success factors, by conducting a extensive use case description of the KM- related practices, analysing information and knowledge dependency, and identifying appropriate KM metrics to be used to measure the KM practice in the business unit.

Phase 3 aims to determine a suitable method, and to measure the effectiveness of KM within the end-user organization. The measurement method requires the design of a questionnaire and organization of interviews with staff involved in the selected process / business unit. These should be carefully designed using the previously identified metrics, with the following points considered:

- The questionnaire to be designed in a way that helps to translate KM practice into quantifiable metric data.
- Each question should capture important KM practice and have a range of possible answers, which are then translated into a score ranging between 0 and 1.
- The questionnaire must capture the influencing factor that gave the score.
- The questionnaire must enable the employee to suggest how the influencing factors could be improved in order to increase the metric score.

Phase 4 will be dedicated to specifying the KM solution and defining the appropriate KM strategy, which are implemented in Phase 5, trailed and tested in Phase 6, and finally evaluated in Phase 7. The results from the evaluation process will be used to refine the proposed e-Cognos solution, and re-align the proposed strate

4. SPECIFICATION OF THE E-COGNOS SOLUTION

The e-Cognos consortium is adopting an iterative and incremental approach to address the objectives of the project. The work is being carried out across two iterations spanning a 24-month period. This project methodology allows continual assessment and validation of the infrastructure and models, and addresses the potential risks in relation to the implementation of the proposed solutions. Requirement for the proposed system was provided by an analysis of the current business processes and information management practices within the end-user organisations (Phase 1 and Phase 2). The process analyses led initially to the development of models using IDEF0 functional modelling (NIST, 1993) describing the basic KM practices in the participating companies. By abstracting from these models a GKMPM (Generic Knowledge Management Process Model) was designed to determine the high-level KM process activities. At a lower level the Unified Modelling Language (UML) (Object Management Group, 1999) was employed to detail (via Use Cases) the ways in which the e-

Cognos system can be used at a business level, and to derive the required functionality of the system. The ensuing Use Cases were the bridging link between the requirement capture and the system specification with the GKMPM determined by the high-level process activities. At a lower level the Unified Modelling Language (UML) (Object Management Group, 1999) was employed to detail (via Use Cases) the ways in which the e-Cognos system can be used and to derive the required functionality of the system. The ensuing Use Cases were the bridging link between the requirement capture and the system specification. From the Use Cases, the e-Cognos Project used an Object-Oriented approach to system design, which itself is a subset of the Rational Unified Process (Rational Corporation, 2001).

4.1 THE E-COGNOS GLOBAL SYSTEM ARCHITECTURE

The major components of the architecture include the e-COGNOS modelling infrastructure, the e-COGNOS KM services, the e-COGNOS API (which defines an interface to the KM services), and the Wrappers (which provide the mappings between the identified applications and the e-COGNOS API). This is illustrated in

Figure 2.

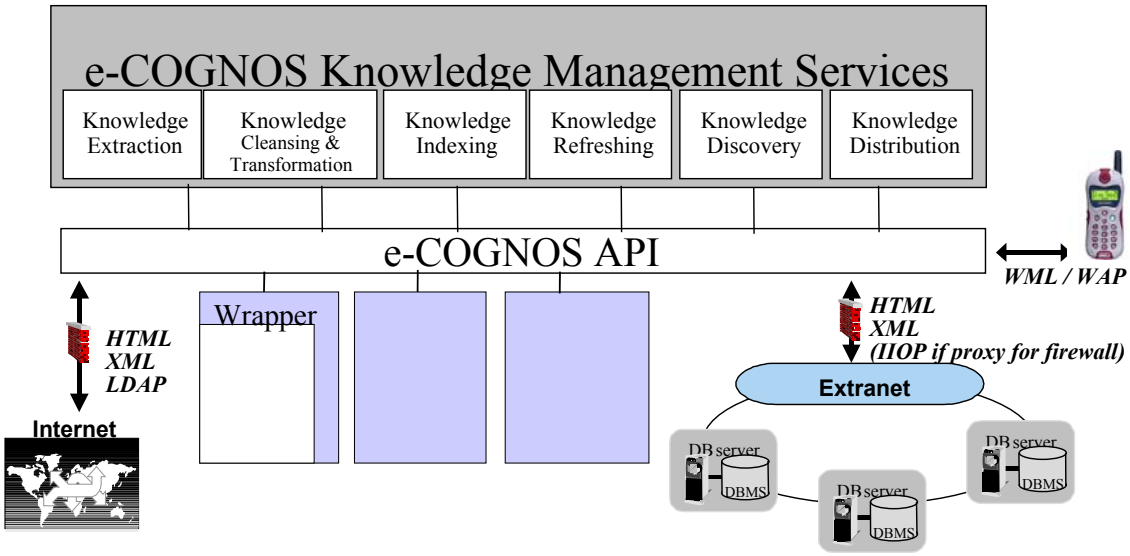

Figure 2: The e-COGNOS Global Architecture

The Generic Knowledge Management Process Model (GKMPM)

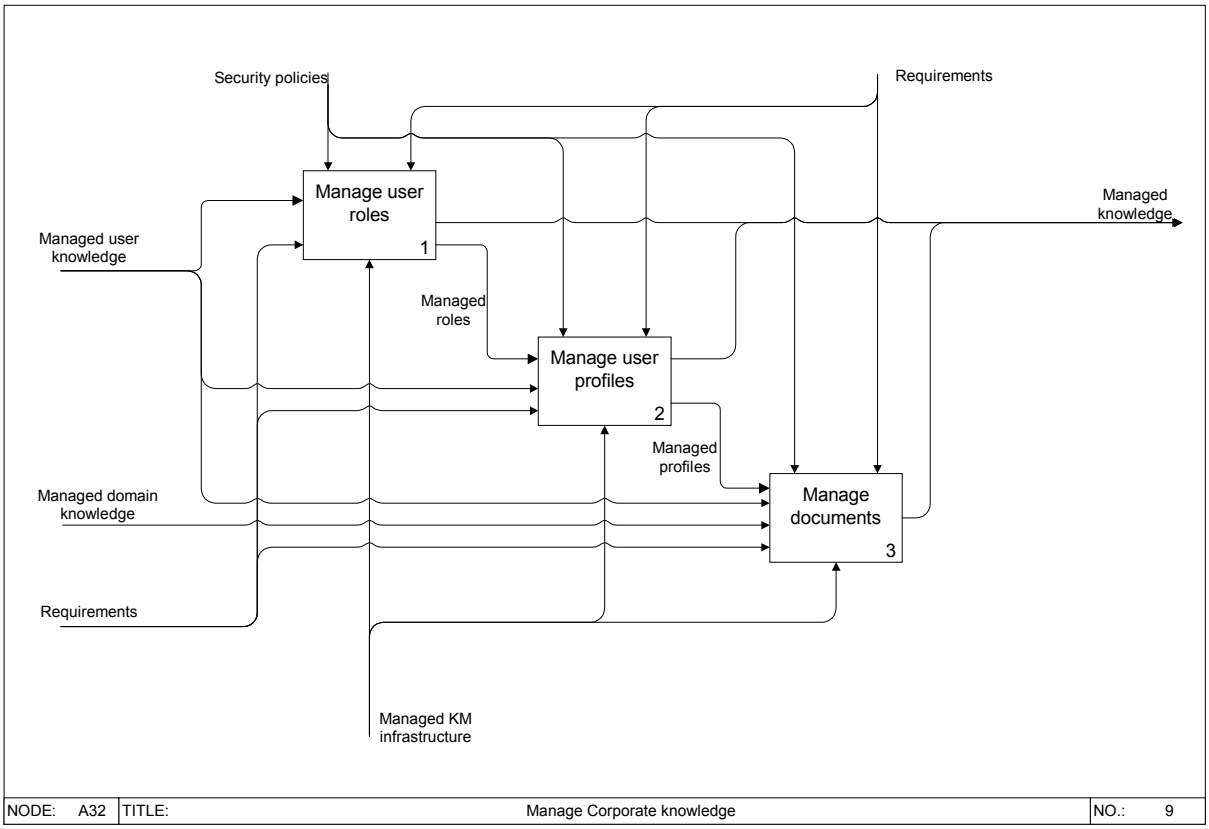

FIG.3: Example e-COGNOS IDEF0 diagram

The GKMPM comprises a set of IDEF0 process diagrams, which form the basis for the on-going design of the e-Cognos platform. This model has been derived from consultation with the industrial end user partners involved in the e-Cognos project, and is decomposed down to the level necessary to fully describe the knowledge related process inherent in the partner businesses. A typical IDEF0 diagram generated during this exercise is depicted in below.

The Use Case Description

The next stage in the methodological approach takes the previously described process models and expands the lowest level process nodes into a set of 'Use Case' descriptions. These use cases detail the way in which the user interacts with the system – effectively, the way in which the system will be *used.* At this point the focus shifts from requirements capture, to system specification and architecture, with the finalised use cases being expanded via object interaction, or 'sequence diagrams'. Use cases are typically grouped into diagrams containing related functionality and interactions, as illustrated below:

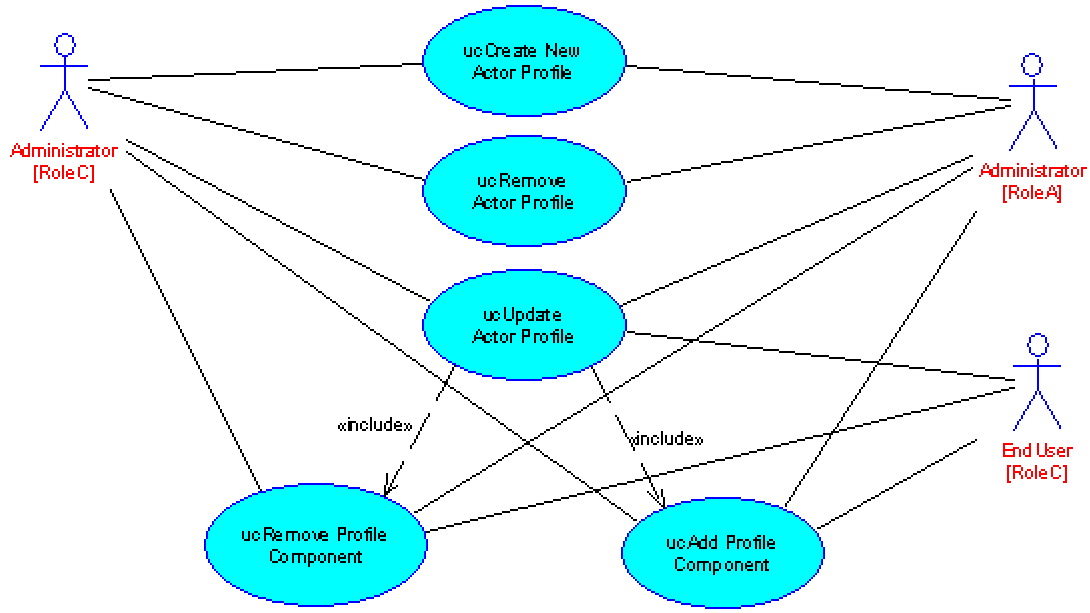

FIG.3: Example e-COGNOS Class Diagram

The Sequence Diagrams

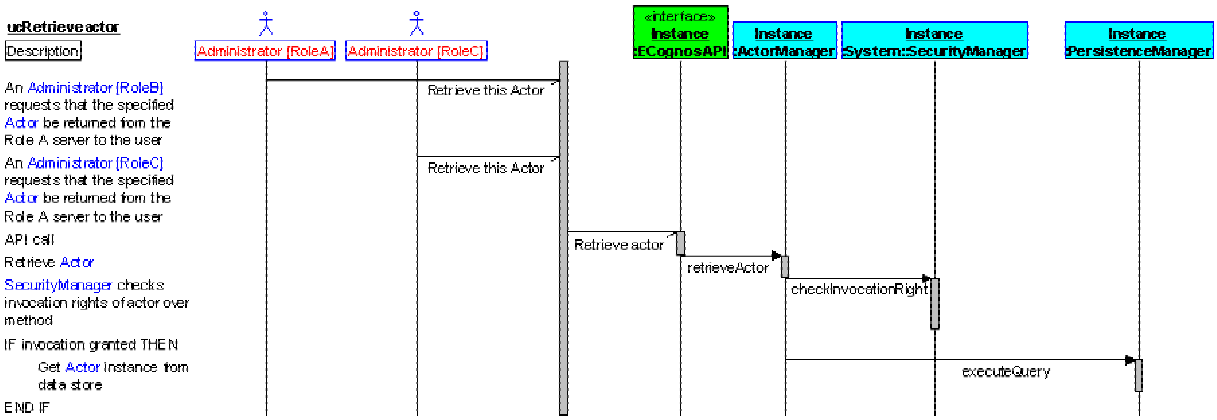

FIG. 4: Example e-COGNOS Sequence Diagram

Sequence diagrams are used to capture interactions from outside the system boundary, together with the internal system component interactions. This step in the modelling process aids in the elaboration of the internal system component architecture and, as it follows a sequential path, highlights timing constraints and essential API calls across the system boundary. A typical sequence diagram is illustrated below:

The e-Cognos Class Diagram

As the system development is following an object-oriented approach, the system components discovered during the sequence diagramming, may then be collected into a system class diagram. Figure 6 shows a subset of the e-Cognos class diagram

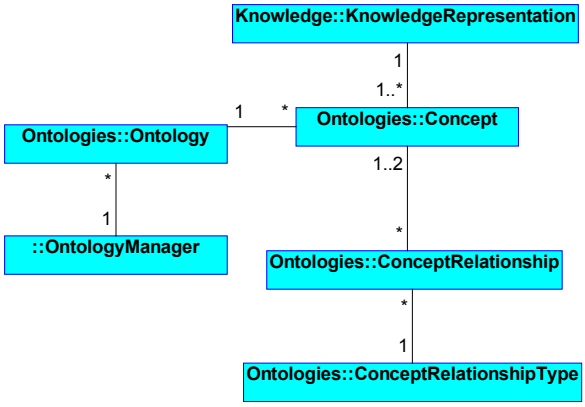

FIG. 5: Subset of the e-COGNOS class diagram

This diagram diagrammatically represents the classes to which all system objects will belong. The class relationships and inheritance etc, are modelled in this diagram, which is used as the basis for the final system code.

A core concept existing within the e-Cognos class model is the 'KnowledgeItem'. At an abstract level, this class represents any potential knowledge, which may include: documents, drawings, personal expertise organisational experience etc. A knowledge item is represented by the collection of ontological concepts which best define it.

The e-Cognos API

The e-Cognos API (application programming interface) is the system level interface, discovered and elaborated during the sequence diagramming exercise, which e-Cognos presents to the outside world. This API takes the form of a set of routines or 'calls' which are fully specified in terms of parameters, which may be passed to, and returned from, the system. This ensures a consistent, predictable interface, which may be used by the e-Cognos user portal and any 'third party' services, which may need to interact with the system.

A typical subset of the e-COGNOS API is shown below:

Table 1: Subset of the e-COGNOS API

Manage Actors	
Call	**Parameters**
registerActor	(Actor actor)
assignRoleToActor	(Actor actor, Role role)
removeRoleFromActor	(Actor actor, Role role)
retrieveActor	(String identifier)
removeActor	(Actor actor)
assignParentToActor	(Actor childActor, Actor parentActor)
listActorProfiles	()
searchActorProfiles	(String searchString)

Towards the e-Cognos Technical Solution

The e-COGNOS consortium conducted a detailed investigation into existing and developing technologies, which could be of use in the implementation of the e-COGNOS infrastructure. As a result of this investigation, a set of technologies was selected for use by the e-COGNOS developers. Further to this, a technical architecture has been adopted, which aims to allow the implementation of these technologies in such a way as to present a robust, open platform that may form the basis for the on-going implementation and development of the e-Cognos infrastructure.

Figure 6 below, forms the single architectural reference for continuing development of the e-Cognos platform, and should be seen as the technical evolution of the global architecture presented in section 4.1. This technical architecture aims to encapsulate the components and functionalities presented in the global architecture and class diagram, with reference to the technologies selected as appropriate for use in e-COGNOS.

A component-based architecture, using the concept of 'services' has been adopted. This will allow the system to use the 'Web Services Model', as described by Glass (2000), to provide the unifying infrastructure, which will enable the sharing and use of services and applications by the e-Cognos platform. The web services paradigm is enjoying strong support from major organisations and is increasingly being used to facilitate cross-organisational interoperation at a network level. Among the advantages conferred by this approach is the ease with which it will allow external services to be used by the e-COGNOS infrastructure, accessed via the published descriptions of these services. This will allow a prospective user of the e-COGNOS infrastructure to select, use and share services via the e-COGNOS infrastructure, according their individual requirements, while still following an agreed and widely accepted protocol for the in the way that these services are accessed. The Java object oriented programming language has been adopted by the e-COGNOS consortium as the primary development language, due its open, widely available nature and extensive industry support.

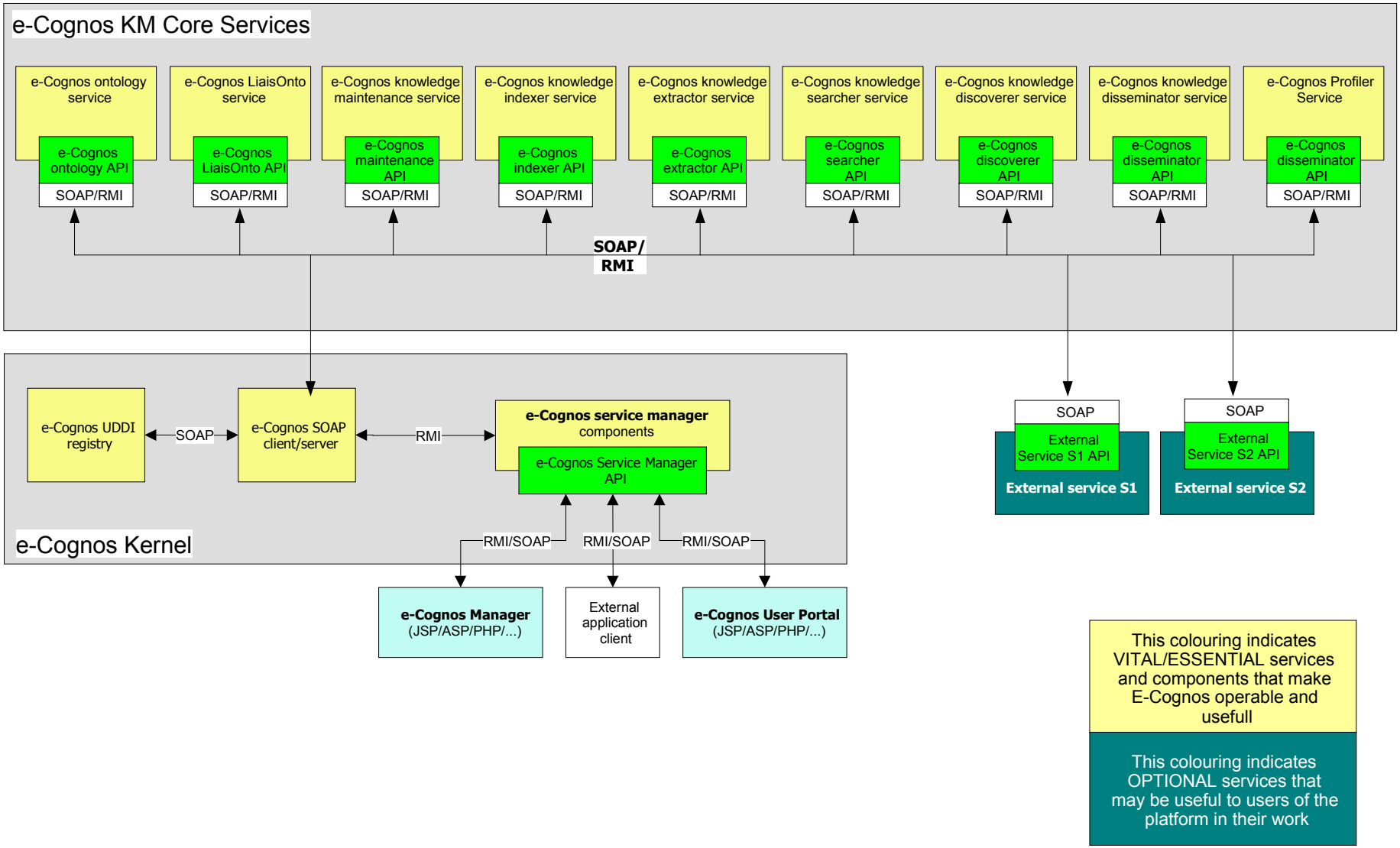

Figure 6: e-Cognos technical architecture

To briefly explain the technical architecture:

Boxes within the "e-Cognos KM core services" section are the services offered as part of the E-Cognos platform. The various service managers will define the API's for the services. Open industry standards are used where possible for these, and the implementation of these standards may impact on the conceptual model and associated diagrams as the development proceeds. Where no standard exists, the API calls defined during the UML modelling exercise can be used directly. The actual implementation of a service may be realised by e-Cognos, or by an external third party with the details of its implementation being of no concern as long as the API is adhered to. Where the consortium implements a service, the class model inside the service will reflect the e-Cognos conceptual model. It is important to note that the service implementations know nothing about each other and do not communicate directly with each other. In essence, we should be able to register them with a public UDDI (Universal Discovery Description and Integration) registry and they will provide some useful functionality to third parties without requiring any reference to the rest of the e-Cognos conceptual model.

The e-Cognos manager and e-Cognos portal represent the various end user interfaces that will be provided by the e-Cognos platform. Currently a portal type application for normal users and an administrative application for administrators are planned, although these functionalities will probably be achieved via a common portal, with the distinction being made as a result of user access rights.

The e-Cognos SOAP (Simple Object Access Protocol) client/server and UDDI registry will be implemented by classes of the conceptual model, which form the core infrastructure of E-Cognos - the part that allows us to register and use the services offered by third parties or ourselves.

As described above, the concept of a 'service' is used heavily by the e-Cognos architecture and the 'Web Services' model is the solution adopted by the e-Cognos to provide the unifying infrastructure, which will enable the sharing and use of services and applications by the e-Cognos platform.

The Web Services model is essentially an object-oriented approach aimed at producing web-based objects for use by programs across business and network boundaries. The three main components of this model are SOAP, UDDI and WDSL (Web Services Description Language). SOAP is an XML based specification for describing standardised request/response messages, UDDI is a physically distributed, logically centralised directory of Web services, and WSDL an XML vocabulary for describing these services and their providers.

The services shown in Figure 7 are described by an API, which is packaged into calls applicable to a particular service. These API calls form the basis for communication between services and applications (which may include both the e-Cognos user portal and external applications). In e-Cognos, this communication process relies on SOAP and RMI, In the main it is intended that SOAP is used, but certain key services may require RMI for performance reasons. The API calls are also intended to support the integration with the end users' application, as long as these applications are Web enabled and will support integration via the 'Web Services' model.

5. CONCLUSION

Many problems in the construction sector arise because of its barriers to organisational learning. There is a crucial need to create a tradition of 'learning companies' and more specifically for the construction industry; an organisation's only sustainable competitive advantage lies in its ability to learn faster than its competitors to produce world-class construction. Moreover, for an organisation to be successful in today's rapidly changing environment, its capacity to learn must exceed the rate of change imposed on it. If the industry is to improve, construction organisations must integrate learning within day-to-day work processes, in such a way that they not only share knowledge and continuously improve, but also, operate efficiently and effectively in response to their changing environment. As a result, there is a need for construction companies not only to concentrate on implementing effective knowledge management systems but also to incorporate learning into their working processes and practices. Effectively meeting the challenge of organisational learning depends on developing organisational cultures that continually encourage people to cross-functional boundaries, not just to tell each other their news, but also to inquire and to come to greater level of mutual trust and understanding. This is the innovative part of e-COGNOS regarding the organisational and human requirements. Construction companies need to seek alternative ways of enabling a learning culture within which they will not only improve knowledge management and transfer but also allow learning to take place, which will lead to performance improvement and competitiveness.

Multi-skilled and knowledge intensive enterprises are at the very heart of "tomorrow's production systems". The E-Cognos knowledge portal solution will provide keys for organisational issues regarding access and use of knowledge at any level (project, corporate, domain), including knowledge of human resources (skills). It is expected that e-COGNOS will advance the state of the art in the area of Internet-based KM in the construction domain through the provision of innovative solutions for:

- Advanced classification and search functions, user profiling for implementation of personalisation and publish/subscribe mechanisms, and information propagation mechanisms that promote and ensure knowledge consistency within and across project, corporate and domain databases.
- Web-based integration of existing (e.g. databases for manufactured products, and national regulations) as well as emerging systems and data warehouses for the benefit of the European construction industry.
- Development of methodologies and techniques to enhance individual and organisations' capacity to learn, to memorise, to disseminate, to capitalise and to adapt knowledge.
- The management of resources (including human resources) and knowledge in the extended construction enterprise, leading to organisational business process improvement.
- Development and facilitation of integration of new organisational structures and new patterns of work, as well as the codification of KM, in the construction industry.

The results of e-COGNOS will be disseminated through different channels during the project and after its completion. The consortium also intends to establish relationships with the European KM Forum initiative [KM Forum 2001], a standardisation and exchange platform in the domain of knowledge management. Results from the project will also be brought to the ICCI clustering project [ICCI 2001] that has been set up to enhance the co-ordination of research and developments in IST projects targeting the construction sector. It is also planned to set up User Interest Groups in the four project member countries, namely England, Finland, France, and Germany, in order to implicate external construction bodies in the assessment and deployment of the e-COGNOS solution.

6. ACKNOWLEDGEMENTS

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