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2002

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Elaine Ferneley
University of Salford, E.Ferneley@salford.ac.uk

Matthew Wetherill
University of Salford, m.wetherill@salford.ac.uk

Yacine Rezgui
University of Salford, y.rezgui@salford.ac.uk

TOWARD THE CONSTRUCTION KNOWLEDGE ECONOMY: THE E-COGNOS PROJECT

Elaine Ferneley
Information Systems Institute, University of Salford, UK
Tel: +44 (0) 161 295 5507; Fax: +44 (0) 161 745 8169
e-mail: E.Ferneley@salford.ac.uk

Mathew Wetherill
Information Systems Institute, University of Salford, UK
Tel: +44 (0) 161 295 5292; Fax: +44 (0) 161 745 8169
e-mail: M.Wetherill@salford.ac.uk

Yacine Rezgui
Information Systems Institute, University of Salford, UK
Tel: +44 (0) 161 295 5292; Fax: +44 (0) 161 745 8169
e-mail: Y.Rezgui@salford.ac.uk

ABSTRACT

The paper focuses upon the contribution that knowledge management portals can make to the enhancement, development and improvement of professional expertise in the Construction domain. The paper is based on the e-COGNOS project[1] 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. The system architect uses a Construction specific ontology as a basis for specifying adaptive mechanisms that can organise documents according to their contents and interdependencies, while maintaining their overall consistency. e-COGNOS has a web-based infrastructure will include services allowing to create, capture, index, retrieve and disseminate 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

1. INTRODUCTION

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 business processes. The resulting output from these processes is a *one-of-a-kind* product. Over the last

[1] E-Cognos is a European R&D project within Framework V: IST-2000-28671, *Methodology, tools and architectures for electronic consistent knowledge management across projects and between enterprises in the construction domain.* The consortium includes an IT and KM service providers: *ARISEM;* European leading construction companies: OTH, YIT, Taylor Woodrow and Hochtief; and European leading research centres and academic: *CSTB and Information Systems Institute* of University of Salford.

decade, construction companies have invested heavily in the improvement of their business processes. 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. While the construction area is becoming an information intensive industry, 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, of 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 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 information management have been undertaken by large enterprises for their internal needs, leading to proprietary solutions. There is a need to supply the industry, including SMEs, with a generic, modular and open solution that moves from information to knowledge management and 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 is tackling.

2. THE E-COGNOS PROJECT

As shortened product development times and globalization increases competition so increased emphasis has been placed on *knowledge* as the key to competitive advantage (Treece 1999). Since Walsh & Ungson's formative article on organizational learning (Walsh & Ungson, 1991) there have been exponential advances in IT. The evolution of hardware, software, telecommunications and databases has made the capture, storage, retrieval, manipulation and distribution of data a significantly simpler task. Whilst the technology has evolved organisational structures and processes do not appear to have progressed at the same rate (Markus, 2001). Whilst the technology may be able to support knowledge management activities the organisation may not be culturally capable of embracing a knowledge management philosophy (Orlikowski, 1993; Davenport & Prusak, 1998).

Markus (2001) identified four key processes associated with knowledge reuse: knowledge capture, knowledge packaging for reuse, knowledge dissemination and knowledge reuse. Similar cyclical views of the knowledge management process include the seminal work of Nonaka (1995) and the more recent work by Grover and Davenport (2001) which identifies a set of processes involved in knowledge management: knowledge generation, codification, transfer, and realisation of value. In order to be successful, a fully *knowledge lifecycle* ICT should aim to support each process in such a knowledge management cycle.

Additionally, key to the success of such a knowledge lifecycle is the notion of the collaborative enterprise. Organisations have tended to choose either the *codification* approach – store explicit knowledge, or the *personalisation approach* – create a pointer system to those who hold expertise. Codification tends to be more technology focused whilst personalisation aims to produce corporate *yellow pages* that provide a mechanism for connecting people – a people rather than IT centric approach. Knowledge management systems that incorporate both technologies for codifying knowledge and mechanisms to support the social and cultural content in which knowledge sharing practices are embedded may ultimately prove to be more successful.

Therefore, the overall aim of the e-COGNOS project 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, packaging, disseminating and reusing) within collaborative construction environments. The detailed objectives of the project are listed hereafter:

- Identify the specificity of KM activity requirements of European construction companies, as well as the organisational, 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 the creation, classification, indexing, retrieval, and dissemination of knowledge in a secure, tracked and managed environment.
- Develop a infrastructure that supports a user profiling mechanism which accommodates the existing complex information and knowledge interdependencies, recognises intellectual property rights and confidentiality issues and allows incremental refinement of profiles based on peer experiences.
- 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 largely rely on generic core services and integration components already developed within other, completed, Framework V projects.
- 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

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 some of the principles 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.

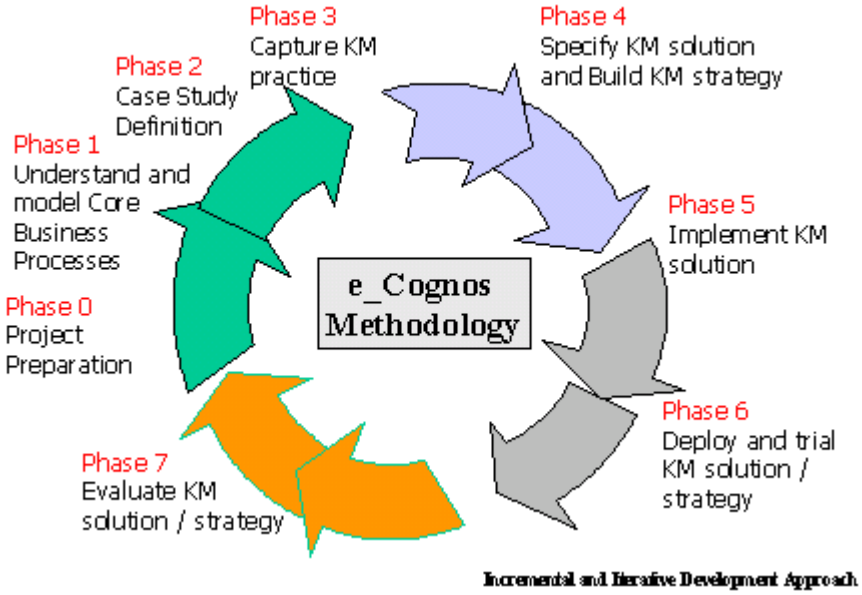

Figure 1: Overview of the e-COGNOS methodology

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. 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 is 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 (identified as a key requirement by industrial partners) to be used to measure the KM practice in the business unit.

Phase 3 aims to determine a suitable method and provide some notion of measurement to identify the effectiveness of KM within the end-user organization. The measurement method may include the use of observation, discussion groups, interviews and questionnaires.

Phase 4 will be dedicated to defining an appropriate KM strategy, which is 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 strategy.

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 The GKMPM determined 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).

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.

The Generic Knowledge Management Process Model (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 figure 3.

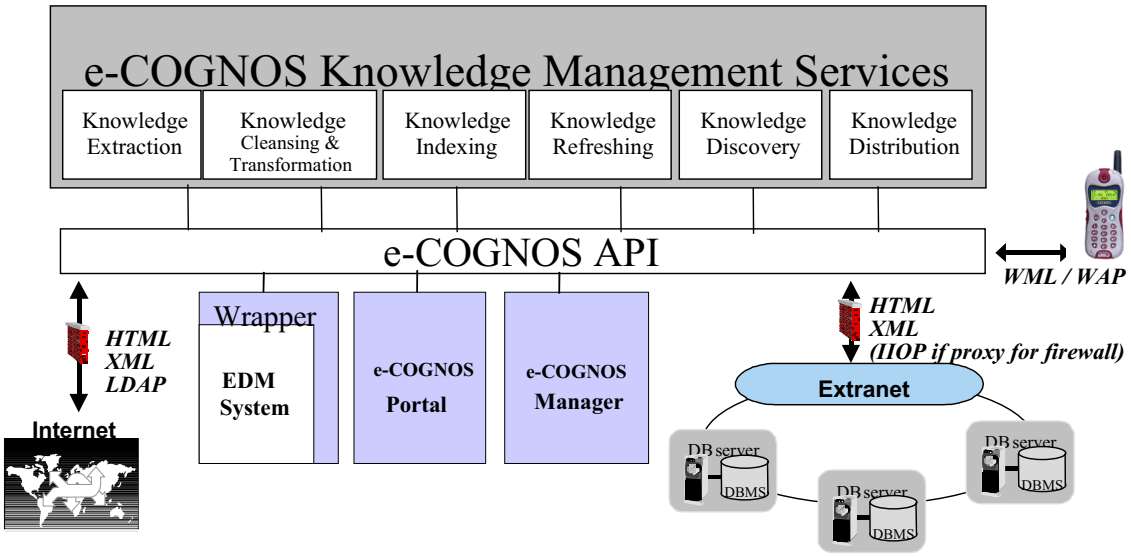

Figure 2. The proposed e-Cognos system architecture

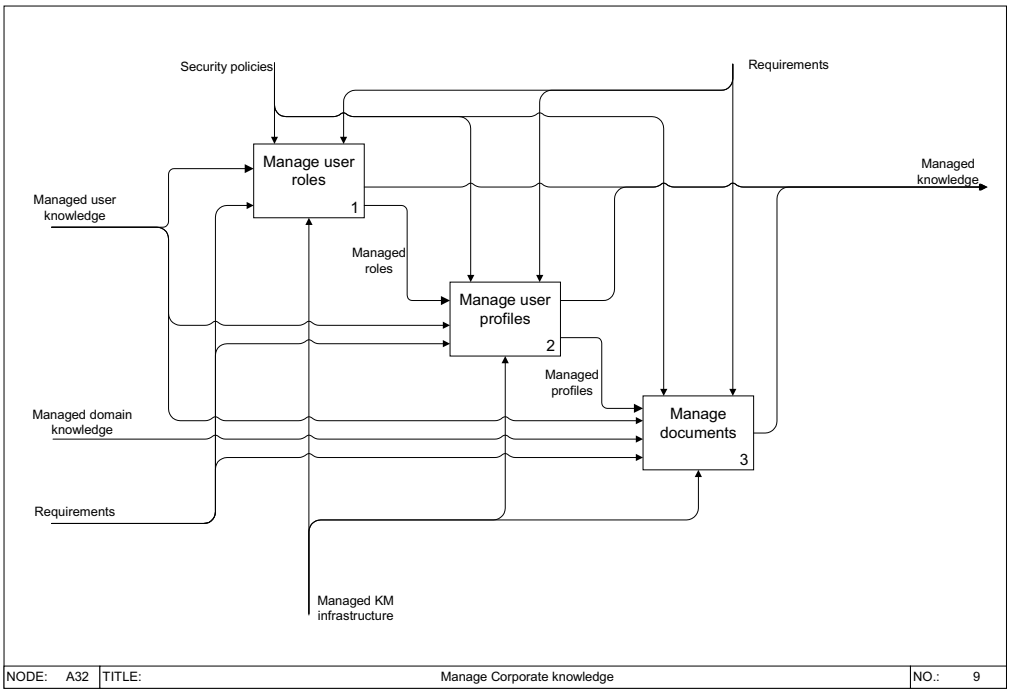

Figure 3. IDEF0 process diagram

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. 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.

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 4 shows a 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.

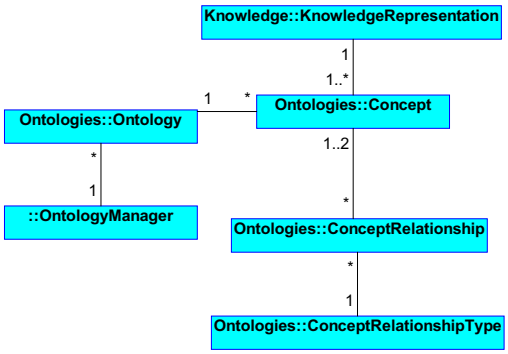

Figure 4. Class diagram

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.

5. CONCLUSION

In common with other domains, many problems in the construction sector arise because of its barriers to organisational learning (Davenport & Prusak, 1998). 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 (Treece, 1999). 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 on incorporating learning to their working processes and practices. Meeting the challenge of organisational learning effectively depends on developing organisational cultures that continually encourage people to cross functional boundaries, not just to tell each other their news but 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 to 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 on 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

The e-Cognos Consortium would like to acknowledge the financial support of the European Commission under the IST programme. The authors would also like to thank the members of staff from CSTB, OTH/Derbi, Hochtief, Taylor Woodrow, YIT, and Arisem for their contribution to the research.

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