Using the semantic web for project information management

D. Ruikar
Ove Arup and Partners, London, UK
C.J. Anumba
Department of Civil and Building Engineering, Loughborough University, Loughborough, UK
A. Duke
BT, Next Generation Web Research, BT Group Chief Technology Office, Ipswich, UK
P.M. Carrillo
Department of Civil and Building Engineering, Loughborough University, Loughborough, UK, and
N.M. Bouchlaghem
Ove Arup and Partners, London, UK

Received November 2006
Accepted May 2007

Abstract

Purpose – This paper has the purpose of exploring the use of the semantic web to support project information management. It aims to discuss the development of a semantic web based framework for shared definitions of terms, resources and relationships within a construction project. These can be used to help and support intelligent collaboration.

Design/methodology/approach – The paper explores the scope of using the semantic web to manage information management processes in the construction industry. It develops the hypothesis that information can be managed using appropriate tools and techniques and develops a roadmap that shows the way in which a solution can be achieved.

Findings – The discussion provides information on the technology that can be used to manage construction project information and the development of ontology is provided in detail.

Originality/value – The paper makes an original contribution of exploring an area (information management tools and techniques) that is at the forefront of discussion in academe and industry in the UK.

Keywords Construction industry, Information management, Production improvement, Project management, Internet

Paper type Conceptual paper

Potential for using the semantic web in project information management

A large number of documents and drawings are generated within the design stage of a construction project. The rapid growth in the volume of project information as the project progresses makes it increasingly difficult to find, organise, access and maintain the information required by project users. Developing mechanisms to manipulate (capture, store, search, retrieve) knowledge generated during projects has always been of importance to construction organisations. People and knowledge are the most

Facilities
Vol. 25 No. 13/14, 2007
pp. 507-524

0263-2772
DOI 10.1108/02632770710822607

important strategic resources of an organisation (Fruchter, 2002). Managing these people and knowledge effectively and using proper technologies to support them, is key to an organisations project success.

Most construction projects teams are established on a temporary contract basis and therefore maintain short-term business relationship. Consultants involved in the same project are sometimes thousands of miles apart and practicing different working methods in accordance with their respective roles in each project. Although the construction industry is very project-oriented in nature, consultants (e.g. architects, designers) working on these projects are typically involved in several projects at the same time. This further complicates the issues related to information management on a project. Efficient and effective information management (IM) is central to project success and requires a buy-in from all project stakeholders. What is important in providing a solution to the IM problem is the realisation of the fact that IM is a combination of people, process and technology. Effective IM ensures that the project data is accessible when it is needed and is provided at a cost and quality that meets user requirements. Finding the correct documentation requires that the documents are provided, structured and maintained to a particular standard.

Current information and communication technologies (ICT) enable the formation of virtual project teams that can work across geographical and time constraints through virtual workspaces. Managing these heterogeneous information sources (particularly ones that contain weakly structured information) remains a difficult task in the construction sector. Currently, some of the most effective IM tools in the building sector are project extranets, workflow management tools and groupware applications for collaborative working (Christiansson *et al.*, 2002). Project extranets build on client-server and web browser technology and enable distributed project team members to share, view and comment on project information in documents and drawings. Such tools are in wide use within the construction sector. However, limitations associated with their document-centric characteristics and limited workflow supports have now been identified (Lai *et al.*, 2003).

It is a requirement of IM tools and techniques to give users the ability to organise information into a controllable asset. Building an internet-based store of information is not sufficient as the context for this information and the relationships within the stored information is vital. These relationships cover such diverse issues related to the stored information database such as relative importance, context, sequence, significance, causality and association (Christiansson, 1998). The potential for IM tools is vast; not only can they make better use of the raw information already available, but they can sift, abstract and help to share new information, and present it to users in new and compelling ways. Although current systems have limitations in providing this functionality, potentially some of these functions can be offered through by the development of applications that are based on use of next generation technologies such as the semantic web.

The current WWW and applications associated with it work well for posting and rendering all kinds of information or holding it within a container such as a web page but provides very limited support for processing them. This is because most web contents are stored in natural language chunks, which makes them very much dependent on the human users during search, access, extraction, interpretation and processing. In response to this, the vision of a semantic web was created by Tim

Berners-Lee in order to enable automated information access and use based on machine-processable semantics of data. Semantic web was defined by him as:

> [. . .] an extension of the current web in which information is given well defined meaning, better enabling computers and people to work in co-operation (Berners-Lee *et al.*, 2002).

The semantic web uses ontology structure for knowledge access. Such structured method to store information supports (information retrieval, extraction and processing. Incorporation of semantic web technologies in the information repository reduces the risk of project failure through better visibility and communication. It also provides users with intelligent access to heterogeneous distributed information, enabling task completion by effective utilisation of available information sources.

This paper explores the potential for using the semantic web in the context of construction project information management. The paper examines the development of an information management strategy for typical construction projects and then the potential provided by the semantic web in supporting intelligent information management on construction projects. It attempts to prove the hypothesis that for effective IM on a project, standard process should be developed to complement the technology that will be used to manage the information. It explores the issues related to the implementation of a coherent IM strategy. It initially focuses on the process issues associated with IM and then explores the potential of the technology itself.

A need for developing a coherent information management strategy for project delivery

As already stated, large numbers of documents and drawings are generated within the design lifecycle of a construction project. These document and drawings are not only shared by all project partners who might be distributed globally but also internally within organisations that create them. The continuous rapid growth in project information volume as the project progresses makes it increasingly difficult to find, organise, access and maintain the information required by project users. This particular problem can be highlighted in two cases.

Document management on site

Besides the document management procedures the formal approval and distribution process for project drawings involves many different parties at different locations. Typically, consultants (architects, engineers etc.) prepare documents/drawings and forward these using fax, courier for site usage. Consultants' documents are received at the site office and typically a document controller dates them when received, keeps the originals and issues copies to project team/site team members. On a typical site office drawings will be logged, copied and distributed to the drawing racks kept on-site. As new versions of drawings are issued superseded drawings will be removed from the racks and filed. When work is to be carried out, photocopies of the drawings are given to the operatives and foremen by the site engineers. It is up to the site engineer to ensure that everyone is using the latest versions and that no-one is working using out of date drawings. The complexities with this process have become more evident with the advent of design and build contracts where the processes of design and construction run concurrently. The current administration of drawings and documents is mainly paper based and requires a high level of control on the versions of drawings being used on-site. The following drawbacks can be highlighted with the current process:

- Delays in the issue of information/drawings can hamper project progress on site.
- Site contractors are managed by the site engineer who has to keep track of who is using what drawing (i.e. what version) and update them when required.
- Although rare the consequences of using out of date drawings if it occurs is very high and very costly. Also, time lost on rectifying the situation can affect the project progress.

The use of web based collaboration tools have helped automate the process of drawing distribution. However, even though they have gone some way to address the complex issue of drawing and document management the use of these systems is still not common onsite. The flow of electronic information comes to a abrupt halt when it reaches the construction site. There are two distinct areas in this process that can benefit from the deployment of semantically enabled mobile technologies; the delivery of drawings to the field and the notification of revisions to drawings.

Information management at the facilities management stage

Potentially, it is even more difficult to search for a particular drawing or document at the facilities management stage after the project has been completed, mainly due to the sheer volume of documents and drawings generated during the project lifecycle. This is also due to the current lack of precise tools for searching the project databases. Facility Managers may have to spend a substantial amount of their time browsing and reading to find out how documents are related to one another within the one or more databases and where each falls into the overall structure of the problem domain. The current search tools available with web based collaboration tools fall short of locating the exact information within a project database. Traditional search engines return ranked retrieval lists that offer little or no information on the semantic relationships among the different documents stored within a database. This can lead to problems at the facilities management stage. Information retrieval traditionally focuses on the relationship between a given query and the information database. On the other hand, exploitation of interrelationships between selected pieces of information (which can be facilitated by the use of ontology) can put otherwise isolated information into a meaningful context. The inherent structures so revealed help users use and manage information more efficiently.

Developing a coherent information management strategy

One of the ways in which the construction IM can be made more efficient is through the tight couplings of project applications that can lead to new levels of interoperability. This interoperability can be loosely defined as the seamless relay of data between different applications within the construction design process without human intervention. The main assumption being that interoperability leads to cost and time reductions. However, as stated by Augenbore (2002) most of these solutions fail due to what can be classified as non-technology issues, e.g. the identification of a clear-cut business case and thus the lack of impetus to invest in these interoperable solutions. Several factors can be attributed to this. These are as follows:

- current data integration solutions do not provide convincing arguments to executive business managers as metrics for inter-company data exchange costs are not well established;
- most solutions are technology-driven rather than business-driven and hence only appeal to middle management with limited business decision power; and
- current solutions are perceived as open-ended and academically-oriented "integrate all" efforts, lacking focus and visible business scope.

For the successful implementation of technology solutions that complement an IM strategy it is required to have processes in place that facilitate workflow and the relay of project information. Both these processes and the technologies would need to be flexible enough to support the development of the information management strategy.

For any construction project it should be recognised that the value of the information created by the design team at the design stage will increase if a whole-life information management approach is adopted. This IM strategy for any project should also be developed in consultation with the different consultants working on the project and should address the client's needs and aspirations. This should be incorporated within the overall project IM strategy (and adjusted iteratively if required). Information management (IM) incorporates the management and stewardship of the project's intellectual property. Successful development and implementation of an information management strategy will deliver value through:

- reducing risks (e.g. reducing rework both during design and construction);
- improving project efficiency (e.g. reducing data re-entry); and
- improving decision support (e.g. progress reporting).

The overall IM objectives should align with the strategic objectives of the project. The IM strategy typically develops as the project progresses to account for emerging information requirements (it hence needs to be flexible to accommodate these changes). Some of the issues related with developing a coherent IM strategy are:

- the IM strategy should align with overall project requirements;
- a whole-life cycle IM approach should be adopted and should be flexible to adopt to changing client requirements;
- all IM systems adopted should enable full collaboration on information by all members of the working on the project;
- all IM systems should be justified by a compelling business case;
- the IM controllers should provide clear and open communication lines for interaction with the end-users; and
- the IM controllers should have clear roles and responsibilities.

Figure 1 illustrates the IM strategy development process.

Defining project-wide procedures and controls such as the setup of the IM team, document control and configuring the appropriate systems to support these is essential to the success of the project. Controlling information within the project should involve, at a high-level representation from the project client, the end-users (e.g. consultants)

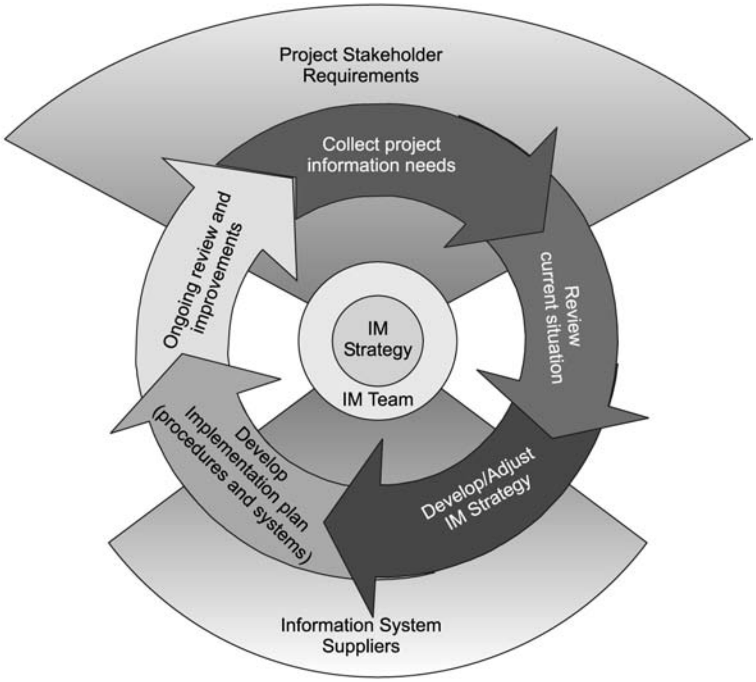


Figure 1.
IM strategy development process

and the IM team. The ICT and IM procedures put in place should align with the existing work methods and keep work-method changes to a minimum.

The system schematic

High-level functionality requirements for a central IM system, common to most construction projects, include:

- *data storage* – central access to data generated/used by the design team;
- *workflow management* – information distribution and design team communication;
- *version control* – ensure the latest version is in use by all;
- *status control* – ensure the integrity of information for appropriate usage; and
- *access control* – to ensure appropriate information security.

It is necessary that such project IM environment/s should be developed and viewed as an integral part of the overall project information management system and should be flexible enough to meet future project requirements The system schematic shown in illustrates (see Figure 2) the idealised situation for a generic construction project, where all data is:

- accessible centrally (through a web-based interface); and
- data is entered once only and then available to multiple applications

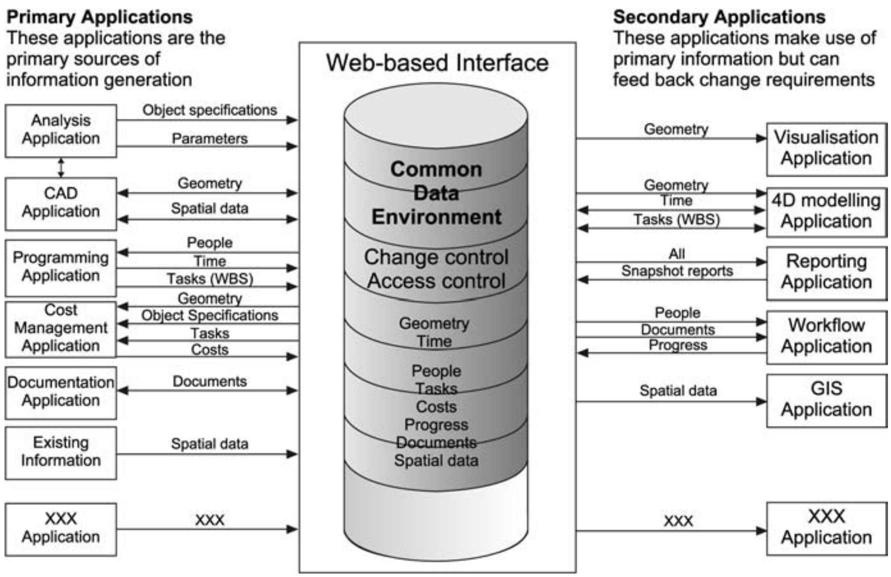


Figure 2.
Information system schematic

This managed project environment may consist of a single repository/database or of several different databases due to application constraints, but the number of these should be minimised as there are application problems associated with storing data in heterogeneous databases that belong to different individuals and organisations (e.g. database standards Oracle, SQL etc.)

Given the evolutionary and iterative nature of design process available information varies from an early phase schematic and idealised to very detailed and precise. This process is supported by document repository that stores the building information. Thus, the mapping of available design information to and from the repository can become time and scenario dependent. This can have a major impact on the way in which project information interoperability can be executed. This is because interoperability is no longer solely a property of the applications, but also dependent on the process. Managing the data exchange thus requires task coordination based on a representation of all design and engineering tasks (preferably captured in scenarios), verification of their inter-dependence and anticipation of expected downstream impacts of alternative ways of design development. Such a dynamic coordination cannot be achieved with currently available information systems.

Most of the currently available project information management tools have limitations as described below though they were designed to deal with operations of relevance to the information management of a particular organisation:

- Information searching is mainly based on keywords search, which may retrieve irrelevant information due to term ambiguity and omit important relevant information when it is stored under different keywords (Ding *et al.*, 2003).
- Manual efforts such as browsing and reading remain the main methods to extract relevant information from textual or other representations. The currently

available software agents fail to integrate information from different sources (Ding *et al.*, 2003).

- Maintaining large repositories of weakly structured information remains a tough and time-consuming task (Ding *et al.*, 2003).

Ontology and the semantic web

To accomplish the vision of the intelligent web, efforts to link the existing web contents to semantic descriptions followed by the creation of a set of applications that can utilise this newly created metadata are ongoing (Fensel *et al.*, 2002; Semaview, 2002). The main driver for the utilisation of semantic web applications is the development of onmtologies. Ontologies are decentralised vocabularies of concepts and their relations to which the existing web contents can refer. These decentralised vocabularies not only define the meaning of web page contents but also the contents of other information resources, including documents (paper-based) and databases. Ontologies are therefore the kernel of the semantic web that allow computers to better categorise, retrieve, query and deduce information from the WWW than the current web technology (Ding *et al.*, 2003; Fensel, 2001). The concept of ontology applied in Artificial Intelligence is to facilitate knowledge sharing and reuse (Fensel, 2001). Ontology is claimed able to provide a shared and common understanding of a domain so that people and various application systems can communicate across the widely spread heterogeneous sources (Maedche *et al.*, 2001). Ontology has been defined as a formal explicit specification of a shared conceptualisation. Thus, it should be machine-readable (Ding *et al.*, 2003; Fensel, 2001). In general, ontology is a graph which nodes represent concepts or individual objects while arcs represent relationships or associations among concepts. The ontology network takes account of properties and attributes, constraints, functions, and rules that govern the behaviour of the concepts (Fensel, 2001). In this respect, ontologies are useful to organise and share information while offering intelligent means for content management as well as enhancing semantic search in distributed and heterogeneous information sources (Fensel *et al.*, 2002). This makes them attractive for information management (IM) within the design and construction context. In accordance with Maedche *et al.* (2001), establishing domain specific ontologies is important for the success and proliferation of the semantic web. Thus, it should also be appropriate to apply such a strategy to the domain of building sector to support better information as well as knowledge sharing amongst the geographically distributed stakeholders. In view of the increasing importance of ontologies, international research in this arena, which has been conducted during the last decade, has presented promising results in the creation of ontology languages (W3C, 2002), ontology editors (Protégé, 2000), reasoning techniques and development guidelines (W3C, 2002). To date, the applications of ontologies are mainly found in e-commerce. A number of EU-funded projects have been undertaken to address knowledge technologies in the context of virtual organisation and business collaboration wherein application of ontologies is the fundamental interest. Amongst them, for example, are ONTOWEB which is a thematic network on ontologies-based information exchange for knowledge management and e-commerce, COMMA which aims at implementing a corporate memory management framework based on agent technologies, OnToKnowledge (2002) that aims at developing tools and methods for supporting knowledge management relying on sharable and reusable knowledge ontologies. By considering the typical collaboration pattern, it is aware that the building sector is also committed to virtual-organisational business relationships, which is mainly project oriented.

Evolution of the semantic web in the construction sector

As the paper has emphasised the construction sector needs to standardise processes to complement technology innovations for IM on projects to maintain its competitiveness. The construction sector must progress to face the challenges of paradigm shift with respect to the use of the innovative ICT as well as the strategy of ontologies.

To overcome the limitations of project extranet is necessary to accommodate the increase of information generated throughout the building life, in particular in the early design phase wherein fragmented design knowledge capture is of importance. The use of diverse professional languages (amongst consultants) impairs communication amongst stakeholders while provoking them to the possibilities of misunderstanding. After being aware of the potential impact, the building sector has taken numerous initiatives to broaden the horizon of communication capabilities that are supported by the internet, and therefore lead to a change of paradigm. In this aspect, several EC funded projects have been conducted to provide the building sector a stepping-stone on the path of paradigm-shift. For example, Diversity, which is a project that aims at supporting and enhancing concurrent engineering practices through allowing teams based in different geographical locations to collaboratively design, test and validate shared virtual prototypes and e-Construct, a project with the aim to improve internet-based communication in e-Commerce and e-business, in the context of communication across national and organisational barriers (e-Construct, 2001). Solutions for transferring and sharing knowledge across ICT systems are therefore the focus of e-Construct. To achieve the objective, a common communication-oriented language, namely bcXML has been defined based on Extensible Markup Language (XML) with building construction meaning aimed at e-Commerce transactions. E-COGNOS (2001), which aims at offering a generic, modular and open solution for knowledge management in the context of collaboration between actors in a construction project started in year 2001. To summarise, the insights of these examples imply that there is an evolution tendency from the document centric internet to a meaning centric semantic web. This shift in focus may meet the requirement of information management practices in the building sector.

As a part of this research to demonstrate the use of the semantic web for project information management and distribution in construction OntoShare, a prototype semantic web based knowledge/information sharing software was used. The OntoShare system was developed as part of the EU project On-To-Knowledge. A higher-level ontology was developed for information sharing and this was then incorporated into OntoShare to demonstrate information and data sharing within construction projects using the semantic web.

Ontology development for information sharing

A high level ontology that could be used for information sharing within a typical building project was developed. This was developed as a routine of concepts and theirs sub-concepts. Such ontology is high flexibility so that it can accommodate an unlimited amount of new ontologies in the future. It is based on the W3C standards for ontology development and can be hence merged into the already existing ontologies. Thus, although it is sector specific it follows common standards and can be extended to integrated horizontally over different sectors. Ontologies should be defined to capture the domain knowledge. The domain in this case was the project management of a building project and the developed ontology is based on the historical data of a typical construction project. This ontology was so developed that the prototype system would cater to functionalities of semantic search of information that was distributed in heterogeneous digital sources. The project-specific ontology consisted of modular parts, for example the "design-process ontology" (Figure 3) and the "team profile ontology" (Figure 4) that described aspects of interest, such as the team profiles and the early design process flow, respectively. The project-specific ontologies are linked with each other using RDF schemas and associated meta-data, to provide the expandable capability of the prototype. The graphical presentation illustrated in Figure 3 and 4 shows the modular characteristic of the ontology network/s, where each concept in the hierarchy was accessible through the uniquely specified URI (uniform resource identifier).

These developed higher-level ontologies are then deployed onto the OntoShare platform.

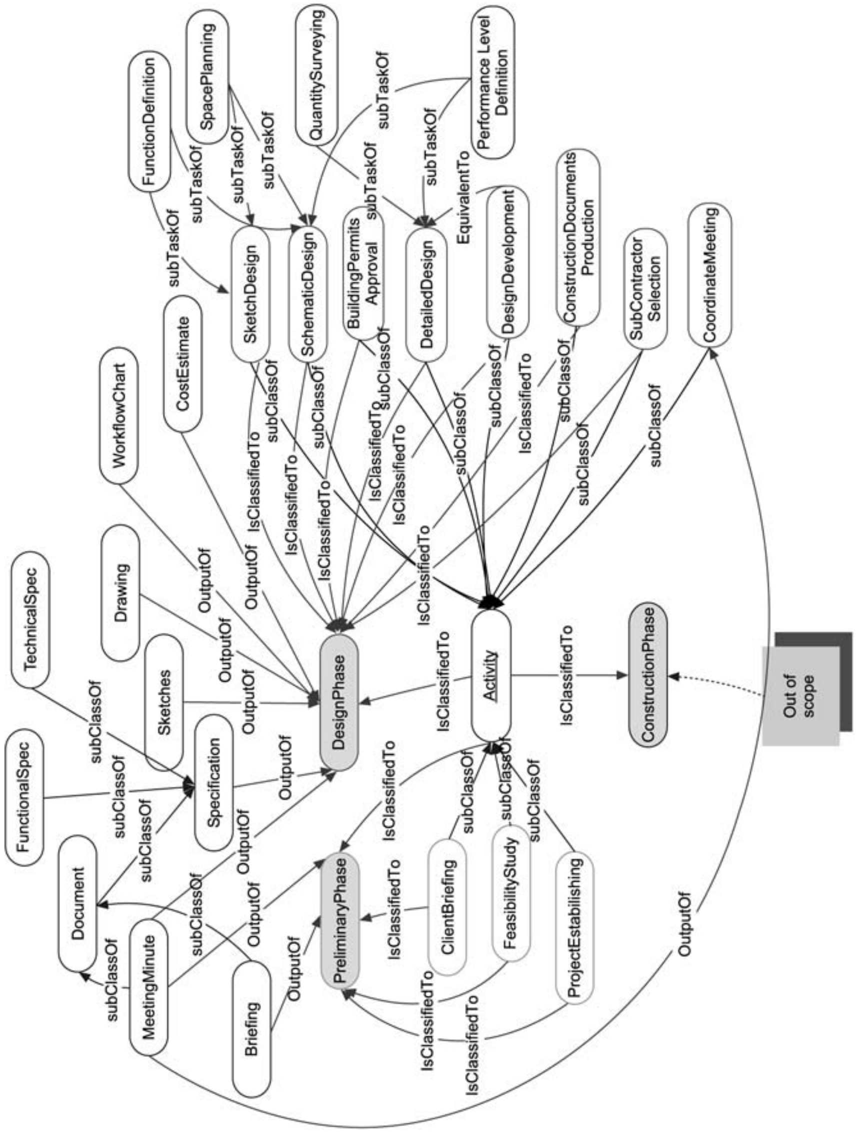
OntoShare is an ontology-based knowledge-sharing environment for a community of practice that models the interests of each user in the form of a user profile. The facilities offered by OntoShare could be used to enhance existing knowledge management systems with the direct delivery of information to users, tailored to their specific interests. In OntoShare, user profiles are a set of topics or ontological concepts (represented by RDF classes and declared in RDF(S)) in which the user has expressed an interest. OntoShare has the capability to summarise and extract key words from web pages and other sources of information shared by a user and it then shares this information with other users in the community of practice whose profiles predict interest in the information.

OntoShare is used to store, retrieve, summarise and inform other users about information considered in some sense valuable by an OntoShare user. This information may be from a number of sources: it can be a note typed by the user him/herself; an intranet page; or copied from another application on the user's computer.

In OntoShare, users can define their profile by subscribing to a set of concepts that are organised in the ontology. The membership to a particular concept is shown in the OntoShare user interface by a red flag icon (see Figure 5).

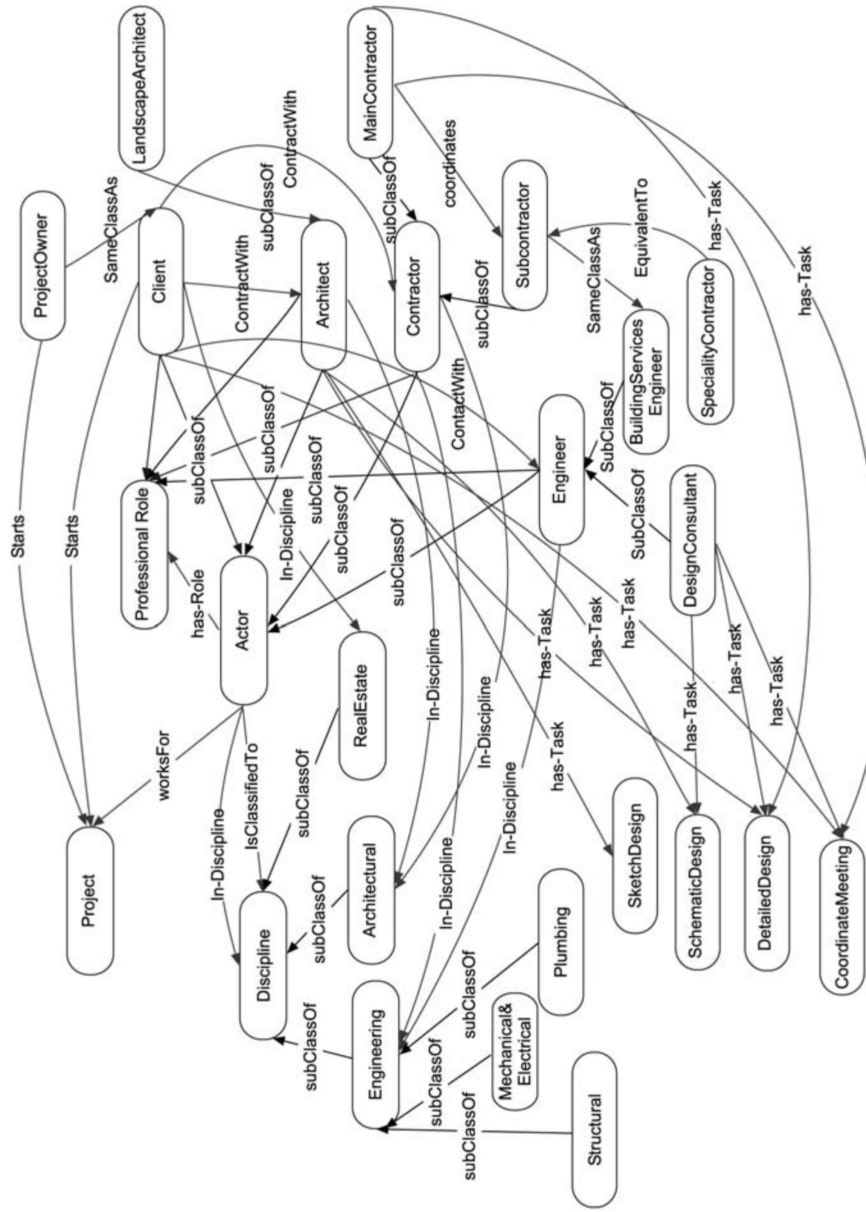
Profiles (user profiles) can be created within OntoShare that represent the different consultants and their work-streams on OntoShare. The user can then subscribe to the different concepts within the defined ontology. The users OntoShare also modifies a user's profile based on their usage of the system, seeking to refine the profile to better model the user's interests.

When a user finds information of sufficient interest to be shared with their community of practice, a 'share' request is sent to OntoShare via the Java client that forms the interface to the system. OntoShare then invites the user to supply an annotation to be stored with the information. Typically, this might be the reason the information was shared or a comment on the information and can be very useful for other users in deciding which information retrieved from the OntoShare store to access. At this point, the system will also match the content being shared against the concepts



Source: Adapted from Lai *et al.* (2003)

Figure 3.
Design process ontology



Source: Adapted from Lai *et al.* (2003)

Figure 4.
Team profile ontology

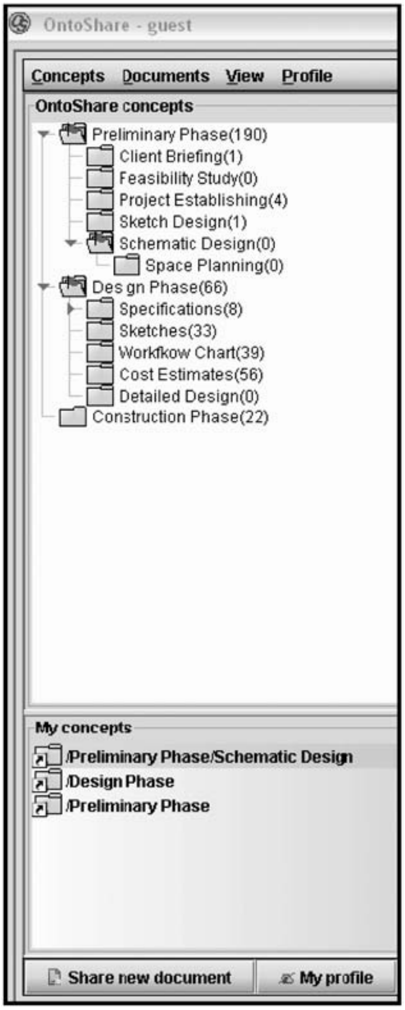


Figure 5.
OntoShare concepts representing the developed ontology

(ontological classes) in the community's ontology. Each ontological class is characterised by a set of terms (keywords and phrases) and the shared information is matched against each concept using the vector cosine ranking algorithm. The system then suggests to the sharer a set of concepts to which the information could be assigned. The user is then able to accept the system recommendation or to modify it by suggesting alternative or additional concepts to which the document should be assigned.

When information is shared in this way, OntoShare performs four tasks:

(1) An abridgement of the information is created, to be held on the user's local OntoShare server. This summary is created using the ViewSum text summarisation tool. The summariser extracts key theme sentences from the

document. It is based on the frequency of words and phrases within a document. Access to this locally held summary enables a user to quickly assess the content of a page from a local store before deciding whether to retrieve the (larger amount of) remote information.

(2) The content of the page is analyzed and matched against every user's profile in the community of practice. As when recommending concepts to the user, the vector cosine ranking model is used: here, however, the shared information is matched against the set of terms (words and phrases) created from the union of all terms associated with the concepts to which has user has subscribed (i.e. the concepts which make up the user profile). If the profile and document match strongly enough, OntoShare e-mails the user, informing him or her of the page that has been shared, by whom and any annotation added by the sharer.

(3) The information is also matched against the sharer's own profile in the same way. If the profile does not match the information being shared, the system will suggest one or more concepts that strongly match the shared information that the user can then add to their profile. Thus OntoShare has the capability to adaptively learn users' interests by observing user behavior.

(4) For each document shared, an instance of the class Document is created, with properties holding metadata including keywords, an abridgement of the document, document title, user annotation, universal resource locator (URL), the sharer's name and date of storage.

A user can elect to subscribe to as many concepts as they like at any stage of the hierarchy. They can also be informed about information that is added to any sub-concepts of concepts that they have subscribed to. The user's profile is then defined as a list of concepts. As documents are added to the system, the user is only informed if the document is added to a concept to which they have subscribed.

As demonstrated in Figure 6 over time the addition of items to the OntoShare store will result in a knowledge base where the items are organised as instances of the

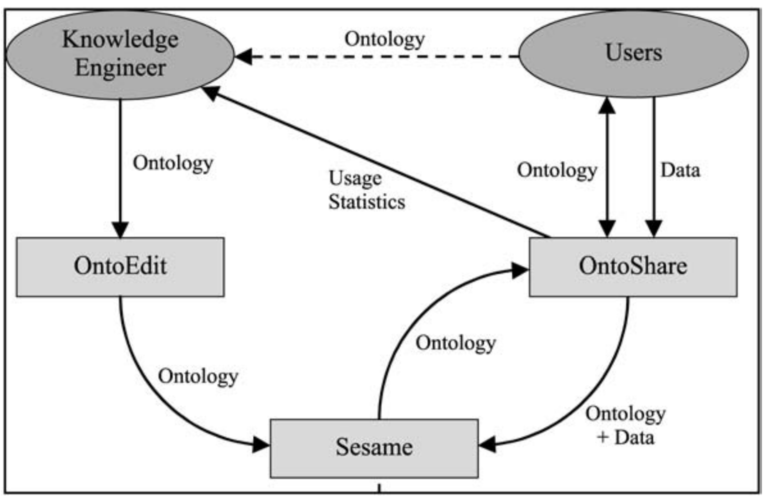


Figure 6.
Ontology evolution

concepts in the ontology. As well as documents and concepts, this rich ontology contains information about users, comments on documents, when documents were added, etc. OntoShare expresses this knowledge base in RDF (resource description framework) and uploads it to Sesame (RDF data repository). Once in Sesame, this (effectively marked-up) knowledge can be exploited by other applications such as search engines.

OntoShare facilitates access to project information and automatic sharing of project information. It has the following benefits:

- *Automated notification:* When information is uploaded into OntoShare the system checks the profiles of other users in the project team. If the information matches a user's profile sufficiently strongly, a notification (SMS or e-mail) can be automatically generated and sent to the user concerned, informing the user of the discovery of the information.
- *Searching and accessing information:* Users (mobile workers) can supply a query in the form of a set of key words and phrases in the way familiar from WWW search engines. The application then retrieves the most closely matching drawings/documents held in the project database.
- *Personalised information:* A user can also ask the application to display documents/drawings that are of high priority to the user. The system then interrogates the project database and retrieves the most recently stored information. It determines which of these best match the user's profile. The user is then presented with a list of links to the most recently uploaded information, along with a summary, annotations where provided and date of storage, the sharer and an indication of how well the information matches the user's profile.

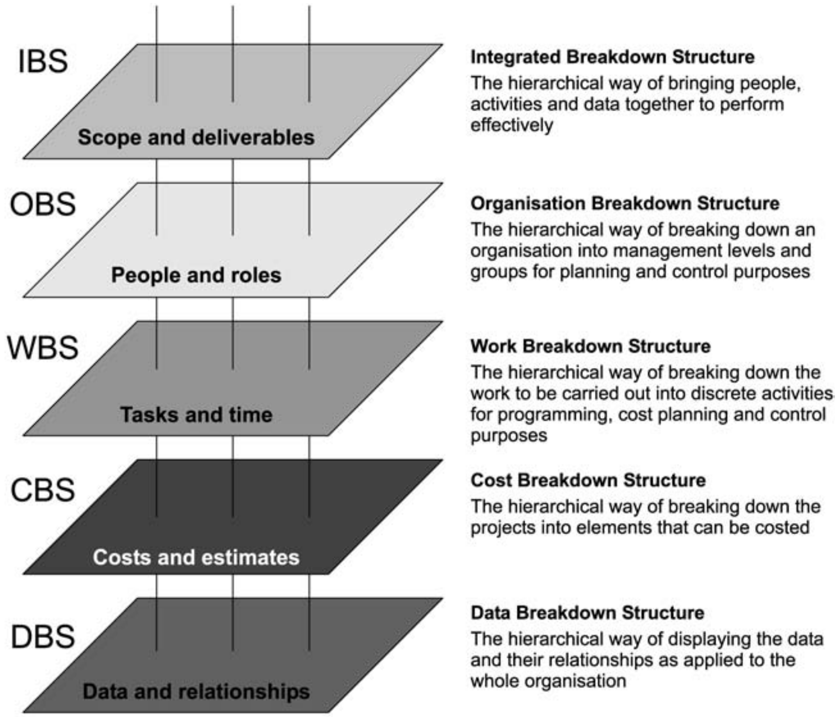
This section has shown that there are benefits in adopting semantic web applications for IM on construction projects. However, before adopting these new technologies the industry needs to have standardised methods of producing, distributing and archiving information in place to derive the full technological benefits associated with the semantic web. The next section looks at some of these interoperability issues.

Project interoperability issues

As seen from the semantic web application, using this technology depends deploying a highly structured method of storing project data. In order to achieve the interoperability outlined in the schema above, the following needs to be put in place:

- The creation and adoption of an integrated breakdown structure (Figure 7) providing a framework for project-wide classification thus easing data transfer between activities (and hence applications). This needs to be in terms of data, cost, tasks, people and project scope.
- Consistent data/information (including metadata) creation procedures adopted by all members of the design team.

Development of these criteria is essential for the successful implementation of a semantic web based application for information exchange.



Source: Adopted from Avanti (2006)

Figure 7.
Creating an integrated breakdown structure

Conclusions

Application of the semantic web technologies (OntoWise), both in context interpretation and at application and services layer allows for better understanding of contextual meaning and their relationship. Better context awareness has the potential to cause a paradigm shift in construction management practices, by allowing construction workers access to context-specific data and services on an as-needed basis. The knowledge of such contextual information will allow better monitoring of the current status of a project (the tasks completed) and the velocity with which the project is moving ahead (against the project plan).

To realise the real potential of technologies such as semantic web-based services for mobile computing in the construction industry these new ICT's need to satisfy the constraints introduced by technological complexity, cost, user needs and interoperability. Further, the effectiveness of the semantic web relies on the development of shared ontologies and semantic standards to ensure increased interoperability across devices, platforms and application. At present construction enterprises perform their tasks in different ways, using different terminologies and modes of operation to perform day-to-day tasks. Hence, the full realisation of the vision of wireless and semantic web-based integration of construction services is possible only when the construction industry agrees on common standards and ontologies for process and product description. These ontologies need to be developed and a common standardised ontology needs to be developed and extended industry-wide.

The IM strategy for a project, and hence system selection, should be guided by the project stakeholder's requirements. An analysis of key project information flow will highlight areas of potential data duplication, which may lead to data re-entry and/or inconsistencies in data used resulting in rework. Understanding the project's information needs will also reduce the likelihood of implementing systems with redundant functionality or unsuitable for later in the project lifecycle. With all of these challenges to address, the success of a major project is determined by factors beyond just the traditional project management scope of time, cost and quality. These projects demand an exceptional management approach – one that is both strategic and autonomous.

References

Augenbroe, G. (2002), "Trends in building simulation", *Building and Environment*, Vol. 37 No. 2002, pp. 891-902.

Bernes-Lee, T., Handler, J. and Lassila, O. (2001), "The semantic web: a new form of web content that is meaningful to computers will unleash a revolution of new possibilities", *Scientific American*, Vol. 284 No. 5, pp. 34-43.

Christiansson, P. (1998), "Using knowledge nodes for knowledge discovery and data mining", in Smith, I. (Ed.), *Lecture Notes in Artificial Intelligence 1454: Artificial Intelligence in Structural Engineering. Information Technology for Design, Collaboration, Maintenence, and Monitoring*, Springer-Verlag, Berlin, pp. 48-59.

Christiansson, P., Dalto, L.D., Skjaerbaek, J.O., Soubra, S. and Marache, M. (2002) in Turk, Z. and Scherer, R.J. (Eds), "Virtual environments for the AEC sector – the diversity experience", in *Proceedings of eWork and eBusiness in Architecture, Engineering and Construction, ECPPM Conference 2002*, pp. 49-55.

Ding, Y., Fensel, D. and Stork, H.-G. (2003), "The semantic web: from concept to percept", *Austrian Artificial Intelligence Journal (ÖGAI)*, Vol. 22 No. 1.

e-COGNOS (2001), *IST-2000-28671 D2.1 e-COGNOS Base Technology Selection*, available at: www.e-cognos.org/Downloads/WP2/e-COGNOS%20D2.1.pdf

e-Construct (2001), *IST-1999-10303 D103 Final Edition of the bcXML Specification*, available at: www.econstruct.org/6-public/bcXML_CD/PublicDeliverables/d103_v2.pdf

Fensel, D. (2001), *Silver Bullet for Knowledge Management and Electronic Management*, Springer, Berlin.

Fensel, D., Bussler, C., Ding, Y., Kartseva, V., Klein, M., Korotkiy, M., Omelayenko, B. and Siebes, R. (2002), *Semantic Web Application Areas*, available at: www.cs.vu.nl/ ~ mcaklein/papers/NLDB02.pdf

Fruchter, R. (2002), "Metaphors for knowledge capture, sharing and reuse", in Turk, Z. and Scherer, R.J. (Eds), *Proceedings of the eWork and eBusiness in Architecture, Engineering and Construction, ECPPM Conference*, Vol. 2002, pp. 17-26.

Lai, Y.-C., Carlsen, M., Christiansson, P. and Svidt, K. (2003), "Semantic-web supported knowledge management system: an approach to enhance collaborative building design", in *Proceedings of the ASCE Nashville 4th Joint Symposium on IT in Civil Engineering, Nashville, Tennessee, 15-16 November*.

Maedche, A. and Staab, S. (2001), "Learning ontologies for the semantic web", *IEEE Intelligent Systems and Their Applications*, Vol. 16 No. 2, pp. 72-9.

OnToKnowledge (2002), available at: www.ontoknowledge.org

Protégé (2000), available at: http://protege.stanford.edu/index.html

Semaview™ (2002), *Concept to Reality What the Emerging Semantic Web Means to your Business*, available at: www.semaview.com

W3C (2002), RDF "Vocabulary description language 1.0: RDF schema", W3C Working Draft 30 April, available at: www.w3.org/1999/02/22-rdf-syntax-ns#

Further reading

Avanti (2002), available at: www.avanti-construction.org/docs/Avanti%20-%20Latest%20Project%20Information.pdf

Christiansson, P., Svidt, K., Skjærbæk, J.O. and Aaholm, R. (2001), "User requirements modelling in design of collaborative virtual reality design systems", paper presented at the International Conference on Construction Information Technology, Mpumalanga, South Africa, 30 May-1 June, pp. 40/1-40/12.

Davies, J., Fensel, D. and Van Harmelen, F. (2003), *Towards the Semantic Web: Ontology-driven Knowledge Management*, John Wiley & Sons, New York, NY.

Zarli, A., Katranuschkov, P., Turk, Z., Rezgui, Y. and Kazi, A.S. (2002), "Harmonisation of the IST research and development for the European construction industry: the ICCI project", in *Proceedings of the eWork and eBusiness in Architecture, Engineering and Construction, ECPPM Conference 2002*, pp. 33-40.

Corresponding author

D. Ruikar can be contacted at: darshan.ruikar@arup.com