POTENTIAL APPLICATION OF THE SEMANTIC WEB IN CONSTRUCTION

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Low efficiency and poor understanding of project information communication among distributed partners is a major hurdle for the success of construction projects. A machine-understandable information processing approach, the Semantic Web, provides a possible solution to this problem. The Semantic Web supports universal information exchange, such as combining the context into information entities, optimising the organization of information for navigation, supporting machine learning, and realizing intelligent document retrieval and image retrieval. Despite the rapid development of the Semantic Web in recent years, there are very few related research projects in the filed of construction industry. On the other hand, the great benefits obtained by using the Semantic Web in other industries provide good examples to construction. This paper reviews the key concepts, functions and applications of the Semantic Web, and discusses how it improves the performance of construction information management and its potential applications in design, procurement, Communication, Change and Claim Management, and the benefits of applications.

Keywords: Semantic Web, Information Communication, Construction Industry

INTRODUCTION

The construction industry is facing an increasing demand for information communication between its global distributed partners. Current Web-based information management systems do not reach their full potential because the Internet is a “web of links”, which is a place where data can only be shared and processed by humans. Therefore, it is inconvenient to resolve problems when project partners cannot meet together synchronously, or use different languages, or have different understanding of an issue. This leads to low efficiency in communicating project information and facilitating collaboration among partners, which are major hurdles for the success of projects.

One of the approaches that attempts to solve above problems focuses on making the Web understandable by both machines and humans. The term, “Semantic Web”, or “Web of meaning”, is used to describe such a Web, in which information is given well-defined meaning. Both computers and people can work in cooperation (Berners-Lee et al. 2001). Since the information on the Semantic Web has a clearly defined meaning, it can be analysed and traced by computer programs. Although programs on the Semantic Web may be designed independently, they will be able to share and process data automatically. It is expected that the Semantic Web could be applied in the construction industry to facilitate building and construction process and resolve the major hurdles discussed above.

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The rest of this paper describes the concepts and architecture of the Semantic Web, with the main focuses on its application to industry in general and construction in particular.

WHAT IS THE SEMANTIC WEB?

Definition

Although the initial idea of a machine-understandable Web appeared in 1989, it was first called the Semantic Web in 2001. Currently, numerous researchers are studying the Semantic Web. Many layers of the Semantic Web and applications in the fields of databases, artificial intelligence and library science are being processed. They aim to "bring structure to the meaningful content of Web pages, creating an environment where software agents roaming from page to page can readily carry out sophisticated tasks for users" (Berners-Lee et al. 2001) .

Tim Berners-Lee (2003), inventor of the current Web and the Semantic Web, defined the Semantic Web as: "The Semantic Web is specifically a web of machine-readable information, whose meaning is well-defined by standards: it absolutely needs the interoperable infrastructure that only global standard protocols can provide".

To achieve the Semantic Web, Web resources should be described in the way that makes their meaning explicit. The following section describes the architecture incorporating meaning to the web resources.

Architecture of the Semantic Web

Tim Berners-Lee outlined his vision for the Semantic Web as a layered architecture (Figure 1). This architecture has been generally accepted and is expected to be developed in the next ten years. In this architecture (Figure 1), the semantic languages are built upon URI (Uniform Resource Identifier) and Unicode, which are already present in the Web. URI became a W3C Recommendation in 1989, providing a means of identifying resources with NS (Namespaces). XML (Extensible Markup Language) and RDF (Resource Description Framework) were considered as two major technologies of the Semantic Web (Berners-Lee et al. 2001). XML became a W3C Recommendation in 1998, and RDF became a W3C Recommendation in 1999.

On the top of RDF there is the Ontology layer. Ontology means the specification of a conceptualisation; which defines terms and relationships between terms, preferably in some machine-readable manner (Hendler 2001). The Ontology layer is in the form of the OWL (Web Ontology Language), which became a W3C Recommendation in 2004.

Proof and trust models and languages are "the most embryonic" (Goble 2003: 551-556). Proof is the provision of explanation - why was certain knowledge inferred. Trust is an attribution of metadata statements. For example, assertions about amazon.com by a customer are more trusted than those of an eBay seller.

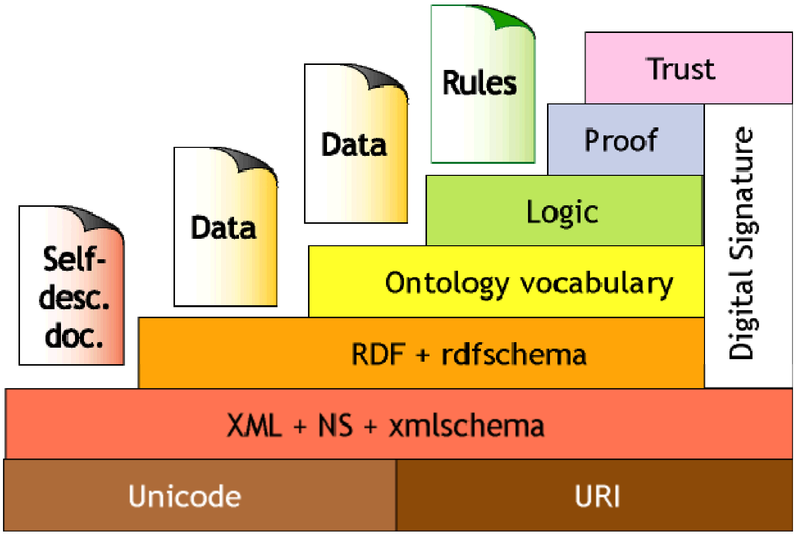

Figure 1: **The Semantic Web "layer cake" as presented by Tim Berners-Lee**

APPLICATIONS OF THE SEMANTIC WEB

The Semantic Web is an extension of the World Wide Web. Science and engineering and commerce will benefit enormously from the Semantic Web. However research, standardization and employment are still needed to ensure it happens (Sean 2001). The current thematic applications mainly focus on knowledge management and Web Services. Meanwhile some prototype systems are being developed for the industrial employment.

Thematic Areas

The implementation of an RDF database, which develops and integrates annotation with data (such as documents), will provide intelligent knowledge retrieval and additional knowledge-intensive services (Karvounarakis et al. 2003) beyond what are currently available using "standard" information retrieval and search facilities. Layers above RDF, such as rules languages and logic interchange, are the subject of many knowledge management prototype systems. These services include information query, intelligent notification (Cost et al. 2001), information retrieval (Shah et al. 2002), collaborative working, data analysis (URL 1) and decision support (Flynn et al. 2002). The Semantic Web then becomes a vast knowledge repository rather than a document collection. There are many approaches to specific information which enable their users to find relevant information. So the risk and expansion of time and money are reduced.

Using flexible data description and ontologies (concept hierarchies, relational structures) of the Semantic Web, different databases can work together automatically. MIT LCS (MIT Computer Science and Artificial Intelligence Laboratory) studied how to realize application integration, which involves importing, exporting and annotating data between different document formats, such as iCalendar, Palm, Outlook, OFX, QIF, telex, mysql, makefile, dpkg, HTML, scrape, .dot and JPG. Many data models and ontology-based visualisation techniques were proposed for encoding semantic information (Harmelen et al. 1999). On-To-Knowledge has developed an ontology-based tool to improve knowledge management (URL 3). This enables different participants (organizations, individuals, or departments) to maintain their own knowledge structure while exchanging information.

With the growing importance of metadata, metadata management developed as well. A Spectacle Workbench was introduced in the book *Knowledge-based Systems* for

verifying semi-structured information and shows how it can be used to validate, aggregate and visualize the metadata of an existing information system (Stuckenschmidt and Harmelen 2003) .
Sesame is one of the first storage and query architectures (Broekstra et al. 2001), that can be based on arbitrary repositories, ranging from traditional Data Base Management Systems, to dedicated RDF triple stores. It has a query engine, which is a powerful RDF/RDF Schema query language.
On the top of the existing infrastructure, machines can access the contents of Web. This technology supports the intelligent agents' work. Better than the current Web, the Semantic Web make more use of the multi-agent system paradigm.

Industrial Applications

The implementation of the Semantic Web provides many Web Services. Some applications have been studied in the following industries:

Electronic commerce transactions
In the field of electronic commerce, suppliers and vendors need to integrate heterogeneous and distributed product descriptions. Different users, buyers and sellers, might use product data from different views. To realize the full power of online e-commerce, automated services are expected. On the basis of machine-processable semantics of data and ontologies, software agents can search for products, form buyer and seller coalitions, negotiate about products, or help to automatically configure products and services according to specified user requirements. (Fensel 2001)

Medical, clinical data linking
There are many current research projects about ontology development for modelling biological, pharmacological, and clinical data. A set of descriptors/characteristics for semantic links used in the medical domain was already produced by the end of 1999 (Schweiger et al. 2003).
Biological information
Some researchers use the Semantic Web to express gene by combining information with it. The project is being carried out by researchers from the Medical Centre and the Department of Computer Science of Vrije Universiteit Amsterdam. The application is already implemented as a Web Application using the Java programming language (URL 2).

Manufacturing
The On-To-Knowledge project, which integrated many partners such as BT, CognIT and Aidministrator (some small-sized companies), and OntoText lab of Srima AI Ltd, applies ontologies to electronically available information in order to improve the quality of knowledge management in large and distributed organisations (URL 3).

Transportation and Infrastructure
Bernstein and Klein(2002) used ontologies in the Semantic Web to describe the internal properties of transportation services, such as the cargo (people, furniture, oil, etc.), the instrument used (car, train, ship, airplane, etc.), and the area of transportation (city, country, international, etc.). These services are often related to each other and make combined services. The semantic interoperability in infrastructure systems is also discussed including efficient interaction; processing and effectively using Geographic Information Systems (GISs) within the civil engineering discipline (Karimi et al. 2003).

POTENTIAL APPLICATIONS IN CONSTRUCTION

Generally speaking, as well as in other industries, in a construction setting, the Semantic Web technology is good for knowledge management and Web Services at various levels and for various activities. It is expected that a construction project will gain great benefits from Semantic Web applications in areas, such as design, procurement, communication management, change management and claim management, taking advantage of sharing a large volume of information between partners and databases.

Design

Data and information generated at the design stage of a construction project reflect the tacit design knowledge. Data could be structured or un-structured. Client's brief concepts, the architect' briefing notes and sketches are mainly informal and not well structured. The final drawings and reports are structured. For example, in the conceptual design, before a common agreement of the project comes out, the client and the architects may use different terms to define an item. And many conceptual construction elements are alternatives in a design. Meanwhile in the detailed design, the same item may have different characters according to its context. For example, the installation requirements of an Ø10 mm bolt are different if it is fixed in a steel beam rather than on an entrance door. The difference leads to the fact that the bolts are different items in the project information management system. However current information management systems cannot describe them. In the Semantic Web, they will be identified by their context when they are first entered into the system.
The architect needs to consider design rules, functional requirements, economic and legal restrictions, and conceptual construction elements. Now, the context of construction elements exists in the mind of architects and they use CAD to design (Kraft et al. 2003). Obviously, it cannot satisfy the need for effective design. To improve the design process performance, numerous initiatives have been under taken. Using the flexible Semantic Web ontology, the context of elements can be attributed to them. So users can efficiently manipulate the specific information no matter how many changes occur during the design. Primary studies on this issue include the mechanism to manipulate (capture, store, search, retrieve) knowledge generated from experiences and the simulation of collaboration amongst the stakeholders from the beginning of a project (Lai et al. 2003).

Procurement

Procurement using the Semantic Web is very similar to E-Commerce. For example, to construct a cable bridge, strands of cable are used. The contractor can instruct his Semantic Web agent to obtain through his Web browser, which may be fixed, handheld or wireless equipments, such as the PDA, laptop, desktop and mobile phone. The agent promptly retrieves information about Ø15.7 mm first class steel cable from the producer's agent, looks up several lists of providers, and checks for the ones meeting the project requirements and low amount of money including both the material price and transportation fee, serving with excellent or very good trusted rating. From the short list, it looks for a match between available volume of production and acceptable price, which are provided by the agents of individual providers through their Web sites. Using keywords with semantics or meaning, the search engine can find most relative terms and provide them to the agent through the Semantic Web. And the agent can also verify the qualification of the providers online. In a few minutes, the agent will present the providers with a bidding plan. If the contractor doesn't like it for reasons such as a provider did few projects using this

type of cable, the agent can redo the search with stricter preferences about provider's experience, and will present a new list soon. Sometimes, there will be warning notes such as the provider is a Korea company. The production standard of this type of cable is a little different from that in UK. The contractor will review the difference and decide that it is acceptable. In this period, the agent works well no matter the provider and the contractor use different languages, locate in different countries and can't meet for the time-lag and geographical distribution.
Meanwhile, the providers can reach more projects without laboured searching and filtering information. The bidding process will be simpler and more accessible both by humans and machines, if the information is written in the language of RDF and ontologies. Those applications in E-commerce can give rich examples to the construction procurement.

Communication, Change and Claim Management
In a large scale construction projects, there are many partners. Each partner has its own knowledge management system. To work together, they cooperate with each other using the common database of the project and share their personal databases as well. Currently most companies write databases in their own format. Meanwhile, a company may handle many projects at any one time. Since sharing data among various databases is troublesome, one resolution technology is the Semantic Web. It provides a framework for sharing definitions of terms, resources and relationships. Then communication will be facilitated and made more effective (Aziz et al. 2003). For example, partners develop and integrate the annotations with data (such as documents) in the knowledge management systems. One day, there will be three work-groups to work in a site. An electrical engineer will check the possibility to next electrical installation. Two plasterers will finish the ground with mortar. And four carpenters will install the wallboards. Using intelligent collaboration application, the on-site agent draws tasks data from project database and workers' data from groups' databases, and works out a plan considering both available space and schedule to process the tasks. Then it transfers the work plan to groups' agent and gets feedback if they agree with this order. Communication between agents will be finished in several seconds if no accident requiring human participation. When work groups enter the site, if their trustworthiness is assured, knowledge system will deliver right documents and drawings to them and empower them to read, add and delete data. After the work is done, they will be discharged automatically.
Since a construction project is unique and creative, there are initiatives, uncertainty and changes during its life time. And most changes will affect the succeeding activities. The flexible structure of the Semantic Web ontology allows adding or deleting items from a chain following a standard process. Any changes (drawings, schedule, materials, or non-confirmations) are followed by a series of subsequent changes and will be recorded as "standard" information and handled automatically. Information is marked-up and linked to others in the Semantic Web. They can be used by machines not just for display purposes, but for automation, integration and reuse of data across various applications (URL 4). The powerful query language of the Semantic Web provides intelligent knowledge retrieval and many knowledge-intensive services.

Potential benefits of the Semantic Web
The machine-processable semantics of Web sources will bring numerous benefits to construction projects.

1. Understandable information manipulation: The improvement of efficiency in the manipulation of information has been stated earlier and results from the nature of the Semantic Web.
2. Multi-agent construction management: With the Semantic Web, both humans and machines participate in processing information in a peer-to-peer environment, and can be regarded as agents. The partners in a construction projects are also agents. They are able to dynamically discover, interrogate and interoperate resources, building and disbanding problems, discovering new facts, and performing tasks. Therefore, the organization of a project is more flexible. Agent-based organization can lead to many additional benefits (Ren and Anumba 2004).
3. Multimedia-based recommendation and visualization: Links and annotations of the data in the Semantic Web make it possible to process un-structured data. Therefore, multimedia data are also available using Semantic Web ontology. Graphics, sounds, visual documents can be recorded, understood, retrieved, compared, and deleted by machines as well as humans. This suggests that construction management can be made more efficient and effective (Schreiber et al. 2001).

CONCLUSIONS

The paper has introduced the definition and architecture of the Semantic Web. The nature of the Semantic Web, flexible data structure and machine processable metadata, make it a promising tool to handle process problems more effectively and more efficiently. Many current applications are presented from two points of view: the thematic areas and industrial applications. Current application areas, such as electronic commerce, medicine, clinic, biotechnology, manufacturing, transportation and infrastructure, are attempting to use the Semantic Web to meet the challenges in the dynamic and distributed working environment.

This paper also discussed what potential applications will be developed to facilitate construction management and what benefits can be gained. The process of construction is globally distributed and functionally fragmented. Construction information is vital for the success of a construction project. The applications of the Semantic Web in other industries give valuable examples and illustrate its potential to resolve problems in the construction process. Some application areas are outlined in the paper: design, procurement, communication management, change management and claim management. In a Semantic Web environment, universal understandable metadata is used to realize knowledge management and provide various Web Services, which allow correct and instant information sharing between cooperating companies. There are many potential benefits of these in construction.

REFERENCES

Aziz, Z, Anumba, CJ, Ruikar, S, Carrillo, P, and Bouchlaghem, D (2003) *Semantic Web based services for intelligent mobile construction collaboration*. Unpublished, Loughborough University UK.

Berners-Lee, T (2003) *The Semantic Web and Challenges*. http://www.w3.org/2003/Talks/01-sweb-tbl.

Bermers-Lee, T, Hendler, J, and Lassila, O (2001) the Semantic Web. *Scientific American.com*, 17 May, 2001.

Bernstein, A, and Klein, M (2002) Towards high-precision service retrieval. In: Horrocks I, Hendler J (eds.) *First international semantic web conference ISWC 2002,* Sardinia, Italy, 9-12 June, 2002, Springer-Verlag, Berlin, 84-101.

Broekstra, J, Kampman, A, and Harmelen, F van (2001) Sesame: An Architecture for Storing and Querying RDF Data and Schema Information. In: Fensel D, Hendler J, Lieberman H, and Wahlster W (eds.) *Semantics for the WWW*, MIT Press.

Cost, RS, Finin, T, Joshi, A, Peng, Y, Perich, F, Nicholas, C, Chen, H, Kagal, L, Zou, Y, and Tolia, S (2001) ITTALKS: A Case study in how the Semantic Web helps, In: *International Semantic Web Workshop*, 30-31 July 2001, Stanford University, California, USA.

Fensel, D, McGuiness, DL, Schulten, E, Wee Keong, Ng,, Ge, PL, and Yan, G (2001) Ontologies and Electronic Commerce, *IEEE Intelligent Systems,* January-February 2001, Volume 16, Issue 1, 8-14.

Flynn, J, and Dean, M (2002) *DAML experiment plan.* Unpublished, https://www.daml.org/2002/01/experiment/daml_plan_point8.doc.

Goble, C (2003) The Semantic Web: an evolution for a revolution. *Computer Networks*, Volume 42, Issue 5, 551-556.

Harmelen, F van, and Fensel, D (1999) Practical Knowledge Representation for the Web. In: Fensel D (ed.) *Proceedings of the IJCAI'99 Workshop on Intelligent Information Integration*, 31 July,1999, Stockholm, Sweden.

Hendler, J (2001) Agents and the Semantic Web. *IEEE Intelligent Systems.* March 2001, vol. 16, no.2, 30-37.

Karimi, HA., Akinci, B, Boukamp, F, and Peachavanish, R (2003) Semantic Interoperability in Infrastructure Systems. In: Flood I(ed) *Proceedings of The 4th Joint International Symposium on Information Technology in Civil Engineering*, 15-16 November, 2003, Nashville, Tennessee USA.

Karvounarakis, G, Magganaraki, A, Alexaki, S, Christophides, V, Plexousakis, D, School, M, and Tolle, K (2003) Querying the Semantic Web with RQL. *Computer Networks: The International Journal of Computer and Telecommunications Networking*, Volume 42, Issue 5, 617 - 640.

Kraft, B and Nagl, M (2003) Semantic Tool Support for Conceptual Design. In: Flood I (ed.) *4th Joint International Symposium on Information Technology in Civil Engineering*, 15-16 November, 2003, Nashville, Tennessee USA, 1-12.

Lai, Y, Carlsen, M, Christiansson, P, and Svidt, K (2003) Semantic-Web Supported Knowledge Management System: An Approach to Enhance Collaborative Building Design. In: Flood I(ed) *Proceedings of The 4th Joint International Symposium on Information Technology in Civil Engineering*, 15-16 November, 2003, Nashville, Tennessee USA.

Ren, Z, and Anumba, CJ (2004) Multi-agent systems in construction–state of the art and prospects. *Automation in Construction*, Volume 13, Issue 3, May 2004, 421-434.

Schweiger, R, Hoelzer, S, Rudolf, D, Rieger, J, and Dudeck, J (2003) Linking clinical data using XML topic maps. *Artificial Intelligence in Medicine*, May 2003Volume 28, Issue 1, 105-115.

Schreiber T, Dubbeldam, B, Wielemaker, J, and Wielinga, BJ (2001) Ontology-based photo annotation. *IEEE Intelligent Systems*, May/June 2001, Volume 16, Issue 3, 66-74.

Sean, BP (2001) *The Semantic Web: An Introduction*. http://infomesh.net/2001/swintro/, 2001-09

Shah, U, Finin, T, and Mayfield, J (2002) Information retrieval on the Semantic Web. In: Grossman D (ed) *11th International Conference on Information and Knowledge Management (CIKM 2002)*, McLean, VA, USA, 4-9 November 2002, 461-468.

Stuckenschmidt, H, and Harmelen, F van (2003) Generating and Managing Metadata for Web-Based Information Systems. Knowledge Based Systems, 2003. www.cs.vu.nl/~heiner/public/KBS-Final.pdf.

URL 1 http://java1.lmsal.com/

URL 2 http://www.cs.vu.nl/microgenie/.

URL 3 http://www.ontoknowledge.org.

URL 4 *W3C Semantic Web Homepage*. http://w3.org/2001/sw/(8 November 2002).

URL 5 http://www.w3.org/TR/rdf-schema/.

URL 6 *The Resource Description Framework*. http://www.w3.org/RDF/.

URL 7 *The Web Ontology Language OWL*. http://www.w3.org/2001/sw/WebOnt/.