SEMANTIC WEB BASED SERVICES FOR INTELLIGENT MOBILE CONSTRUCTION COLLABORATION

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SUMMARY: *Construction project delivery is highly dependent on the effectiveness of the team put together to execute the project. To provide real time, on-demand intelligent mobile collaboration support for their workers, construction enterprises increasingly need to use powerful wireless devices coupled with the availability of improved bandwidth, to tap into different inter and intra-enterprise data resources. This paper focuses on the synergy between the Semantic Web, Web Services and agent technologies in the provision of such mobile collaboration support infrastructure. A multi-tier architecture is presented, which brings together the necessary technology threads, including the Semantic Web (to provide a framework for shared definitions of terms, resources and relationships) , Web Services (to provide dynamic discovery and integration) and multi-agent technologies (to help mobile worker accomplish a particular task) to support intelligent mobile collaboration. Future deployment scenarios are presented to illustrate the potential benefits for the construction industry.*

KEYWORDS*: semantic web, web services, intelligent agents, scenarios, mobile collaboration*

1. INTRODUCTION

The Construction industry is currently struggling to implement techniques that can reduce project time and cost, and improve productivity and performance. Growing trends of integration and decentralisation in the industry, largely manifested through adopting design build and partnering approaches, has added to these challenges. The need for innovative ways to face these challenges has long been recognized [Latham,1994; Egan, 1998]. Recent years have also seen a movement in the construction industry towards using collaborative processes that leverage the internet platform, thereby allowing participation of the project team, from the very early stages of the project. However these collaborative working solutions are tailored primarily towards the needs of desktop based fixed network client. Collaboration needs of site based staff and other mobile workers are not well addressed. A number of research initiatives in recent years have focused on supporting mobile workers using ICT technologies (Rebolj et al., 2002; Ward et al., 2002; Saidi et al., 2002). However the current state of the art in mobile communications in the construction industry has some underlined limitations, which include:

- From an architectural viewpoint, state of the art mobile communication applications lack cohesion with the existing desktop based ICT infrastructure. In recent years, this issue is addressed through the use of proprietary or open standard APIs (Application Programming Interfaces), resulting in tightly coupled and inflexible systems.
- From a technological point of view, there has been little work to integrate emerging technologies such as the Semantic Web, Web services, Agents, location and context based technologies etc in the construction work environment.
- From a methodological viewpoint, remote collaboration support for mobile workers is currently seen as a “simple” delivery of the relevant information. Information delivery is mainly static and is not able to take into account the mobile worker changing context. Need for dynamic synthesis of contents and context sensitive information provision for mobile workers is not adequately addressed. Commercially available mobile applications for the construction sector are designed primarily for internal off-line use, centring around batch oriented cradle synchronisation. The needs of the mobile workers to have real time access to multiple information resources is not adequately addressed.
- Application of mobile communications in the construction sector is done in a piecemeal fashion. Very often, mobile applications are designed to support a specific high end client e.g. project management, quality assurance, health and safety etc. The selective application of mobile communication technologies often results in a mixed handling of data, where a set of manual and semi-automated processes work together. Very often this mixed handling has a negative impact on the process workflows.

All aforementioned factors affect the value proposition of mobile communications in the construction sector. This paper discusses the role of Semantic Web based services in addressing some of these limitations and in improving cohesiveness and information flow between the construction teams.

The paper is organised as follows. Initially key enabling technologies for intelligent mobile construction collaboration, including semantic web, web services and agents are discussed. This is used as a foundation to present an architecture, which brings together key enabling technologies as a framework to support distributed construction teams. Various future use case scenarios of Semantic Web applications for mobile construction workers are described. Conclusions are presented about the possible future impact on the construction industry.

2. ENABLING TECHNOLOGIES FOR INTELLIGENT MOBILE CONSTRUCTION COLLABORATION

2.1 The Semantic Web

The Semantic Web is an extension of the current Web in which information is given well-defined meaning, better enabling computers and people to work in cooperation. It is based on the idea of having data on the Web defined and linked such that it can be used for more effective discovery, automation, integration, and reuse across various applications (Hendler et al., 2002).The Semantic Web architecture (Figure 1) is still under development, and is based on number of layers, including:

- **XML**, Namespace and Schema layer for defining contents and rules;
- **RDF** (RDF, 2003) is a conceptual data layer on top of XML. RDF is application and domain neutral, and defines a metadata layer and domain specific vocabulary. RDF model can be used to describe anything that has a Universal Resource Indicator (URI);
- **Ontology Vocabulary** is RDF enhancement regarding relations between concepts, description logic etc. Web Ontology Language (OWL) is used as an ontology definition language;
- **Logic layer** define rules for dynamic inference and definition of hierarchies and processing of schemas and instances;
- **Proof and trust layers** involves rating of sources and processes and monitoring of logical steps.

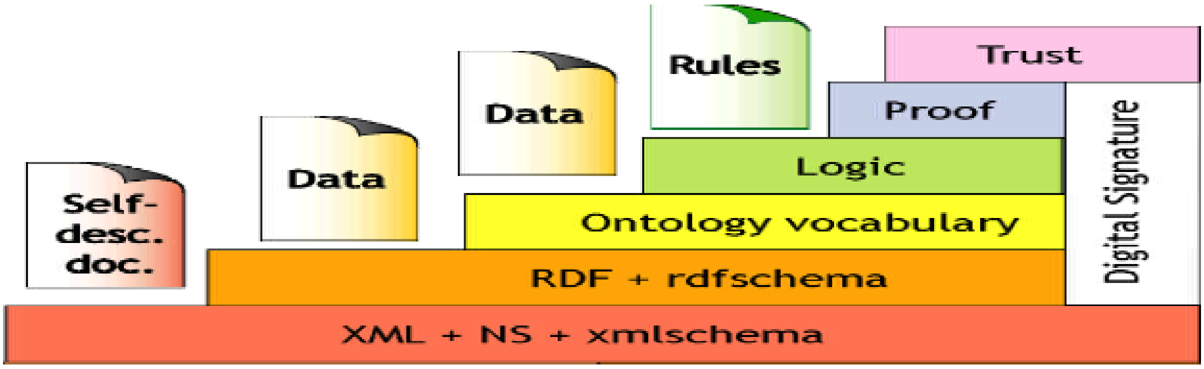

FIG. 1: The Semantic Web Architecture (source: W3C, 2001)

Semantic Web technologies offer considerable benefits in terms of project management, content and document management, knowledge management, supply chain management, integration of distributed applications and services and improved efficiency of construction project delivery (Anumba et al., 2003). Semantic Web-based rules, are starting to be applied in large scale distributed systems in the construction industry (aecXML, 2003; Cerovsek et al., 2002; bcXML, 2003; Cheng et al., 2003).

Semantic Web relevance in supporting the mobile construction collaboration lies in the fact that typical data requirements of construction workers are for either time critical activities (e.g. Request for Information, collaboration with project partners) or for those that can facilitate task completion (e.g. access to drawings, schedules etc.). Semantic description of project resources will enhance mobile construction collaboration in the following ways:

- Deeper understanding of the semantics of document content and project task structure will help the mobile worker in information retrieval, extraction and processing, thereby helping to accomplish elements of a project plan;
- Semantic Web techniques, through the introduction of ontological reasoning, are suitable for flexibly discovering abilities in using information, that was not specifically designed or intended for a particular use case. (Lassila et al., 2003). Thus semantic web technologies will enable worker to use highly specific data and services on as-needed basis;
- Construction enterprises very often perform their processes in different ways. Difference in meanings of terms and mode of operation makes collaboration difficult. Use of shared ontologies and semantic standards will ensure increase interoperability across devices, platforms and applications;
- Separation of presentation and data, as ensured by Semantic Web technologies, will ensure use of same middleware tier for serving mobile and fixed network clients;

However, full realisation of the vision of Semantic Web is possible only when the construction industry agrees on common standards that can be used and extended industry-wide.

2.2 Web Services

Web services are self-contained, self-describing, modular applications that can be published, located and invoked across the Web. Once a Web service is deployed, other applications (and other web services) can discover and invoke the deployed service regardless of operating system or programming language (Kreger, 2001). The key to Web Services is on-the-fly software creation through the use of loosely coupled, reusable software components (Fensel, D et al., 2002).

Typical Web Services architecture consists of three entities (Figure 2): service providers, service requestors (or clients) and service registries. Service providers publish their services through brokers who maintain registries that clients can look up. The API (Application Programming Interface) for registering services is called Universal Discovery and Description Interface (UDDI). This API enables an enterprise to describe its businesses, its services and how they wish to undertake transactions, search for other businesses that provide desired services and integrate with these businesses to undertake a transaction, if desired. Service requestors (Human users or agents) search services in registries and invoke these services using a Web Interface (WSDL).

With the help of information taken from the registries, users invoke the required service, through a Web interface. Simple Object Access Protocol (SOAP) is used to pass object information between applications.

Web services loosely coupled approach suit the construction industry because of temporary, multi-organisation structure of many construction projects, where companies work together for a short period of time. Using Web Services technology, potentially unrelated applications can be linked into composite services, which can than be distributed and accessed through standard internet protocols through wired or wireless devices. In recent years, researchers have demonstrated the applications of web services technology for the construction software application integration (Cheng et al., 2003), construction e-trading services (Cope and Amor., 2002), supply chain integration (Min et al., 2002)and computer aided construction work (Cerovsek et al., 2002).

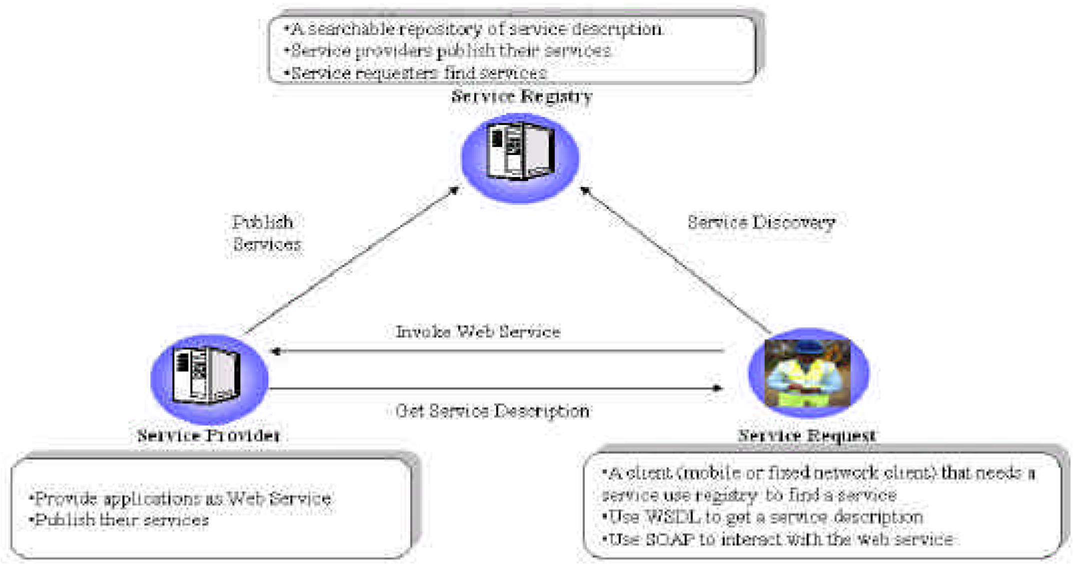

FIG. 2: Key components of Web Service Architecture

2.3 Agent Systems

An agent is a self-contained program capable of controlling its own decision-making and acting based on its perception of its environment, in pursuit of one or more objectives (Wooldridge et al., 1995). In many cases, several agents are required to work in concert, resulting in a multi-agent system (MAS). A typical construction collaboration scenario is inherently distributed in terms of geography, knowledge, function, expertise and information. The notion of (multi) agent based system provides a natural metaphor to match such distribution. In a construction collaborative environment, agents will be essential in addressing the issues of security, negotiation, personalisation and Web Service procurement.

The real power of the Semantic Web will be realised when people create many programs (agents) that collect Web content from diverse sources, process the information and exchange the results with other programs (Berners-Lee et al., 2001). Semantic Web technologies will enable automated agents to reason about Web content, and produce an intelligent response to unforeseen situations. In mobile construction environment, agents will be essential in helping the user highly specific data and services on as needed basis. For instance, delivering answers to short term queries, such as work related tasks, and yet still being aware of long term project goals to be satisfied. These agents will ensure a semantics based linkage to data resources, thereby increasing the level of knowledge identification. Agents can also help in preventing the user from being overwhelmed by irrelevant information, using rule based filtering and adaptation of information to individual context and preferences.

2.4 Semantic Web Based Services

The vision of Semantic Web based services, combines the key technology elements of the Semantic Web, Web Services and Agents. Semantic Web increase the utility of Web Services by providing semantics based brokering capabilities, expressing how terms relate to each other and by enabling dynamic composition of new services

(Hendler et al., 2002). This will enable intelligent access to heterogeneous, distributed information, enabling software products to mediate between user needs and the information sources available. It will also provide mechanisation in service identification, configuration, comparison, and combination (Fensel et al., 2002).

A major initiative in this context is DAML-S (the DARPA Agent Markup Language Services) project, which aims to semantically mark-up the web services, thereby enabling a wide variety of agent technologies for automated Web service discovery, execution, composition and interoperation (Ankolekar et al., 2001). Collectively, Semantic Web-based Services offer new opportunities to enhance mobile construction collaboration, by providing the contextual meanings, personalisation and ontological support (using the Semantic Web technologies) and allowing dynamic discovery and integration (using Web Services standards). This would enable intelligent agents to reason with the heterogeneous data resources. With the emergence of high speed wireless networks, such as Wi-Fi/ GPRS/UMTS, Semantic Web based services can be effectively utilised to give mobile workers access to highly specific data and services.

3. RELATED WORK

The potential of Semantic Web based services in mobile computing realm is explored by many researchers in recent years. Lassila et al (2003) investigated the use of semantic web technologies and emerging DAML-S Web Services (Ankolekar et al., 2001) framework in the development of mobile communication devices i.e. Mobile communication devices which have the capability to automatically configure themselves in the new environments and to combine information and functionality from local and remote sources. Dahlem et al (2002) developed a ubiquitous data management application for mobile devices using web services architecture. Sadeh et al (2002) implemented a semantic web environment for mobile context-aware services. Customisable agents were used to assist mobile workers to automatically discover and access web services. Dogac et al (2002) developed an infrastructure to describe semantically defined Web Services available to mobile devices through agent technology and service registries. Cheng et al (2002) developed an architecture that integrates mobile agents with web services, thereby making web services more convenient and efficient to use on the mobile devices. Toivonen et al (2003) applied semantic web technologies for contextualised content provision to mobile users. The E-Commerce through Wireless dEvices (E-CWE) project (Maamar et al., 2001) investigated techniques and solutions that could support stationary and mobile users in a secure wireless e-commerce environment using web services architecture. The aforementioned research projects have demonstrated the potential of semantic web technologies to enable mobile collaboration at several different levels. In order to realise the vision of intelligent remote construction collaboration, a service architecture is discussed in section 4 which enables semantically enriched information provision to mobile workers.

4. THE INTELLIGENT REMOTE COLLABORATION ARCHITECTURE

The proposed architecture presented in Figure 3, brings together key technology components i.e. Semantic Web, Web Services and Agent Technologies, as a framework for an intelligent remote collaboration platform for supporting distributed construction teams. The architecture is based on multiple tiers, which are explained as follows:

Client Tier: This tier provides users with access to the system. The human interface layer allows intuitive user interaction. The Software interface layer ensures that mobile devices are optimally plugged into construction process workflows, to ensure knowledge mobilisation and ambient information provision to mobile workers. It will also provide users with an ability to invoke web services, thereby enabling interaction with heterogeneous data resources. Web services loosely coupled interface will also provide a reconnect-able infrastructure, responsive to intermittent network connections. User Agents will allow users to personalise contents and services as per their preferences and profiles. Capabilities and preferences associated with mobile devices and agents used by the user will be described using W3C standards, like Composite Capability/Preference Profiles (CC/PP) (CC/PP, 2003). The task specific agent will help worker in accomplishing a specific task by understanding the task context, and by identifying, filtering and accessing the services taking into account the worker context and semantic service description. As logic and data processing resides on the wired network, mobile client is charged with minimal memory and processor consuming tasks.

Access Tier: Access tier provides the vital communication link between the wired back-end and the wireless front-end. The use of Mobile IP application middleware is envisaged, to enable handover and seamless communication between different wireless communication networks such as wireless wide area networks, local area networks and personal area networks. Using Telecom networks, both push and pull mode of interaction can be supported i.e. Information can be pushed through user configured triggers, or mobile worker can pull information through ad hoc requests.

Middleware Tier: An important feature of the proposed architecture is the separation of data from presentation and applications. This separation will allows re-use of the same middle tier for services delivery to wired and wireless clients. Mobile middleware connects desktop based back-end systems with different mobile networks, addressing the limitations imposed by mobility e.g. device limitations, bandwidth variation etc. Use of XML transformation technologies allow support for a wide range of mobile devices with varying form factors.

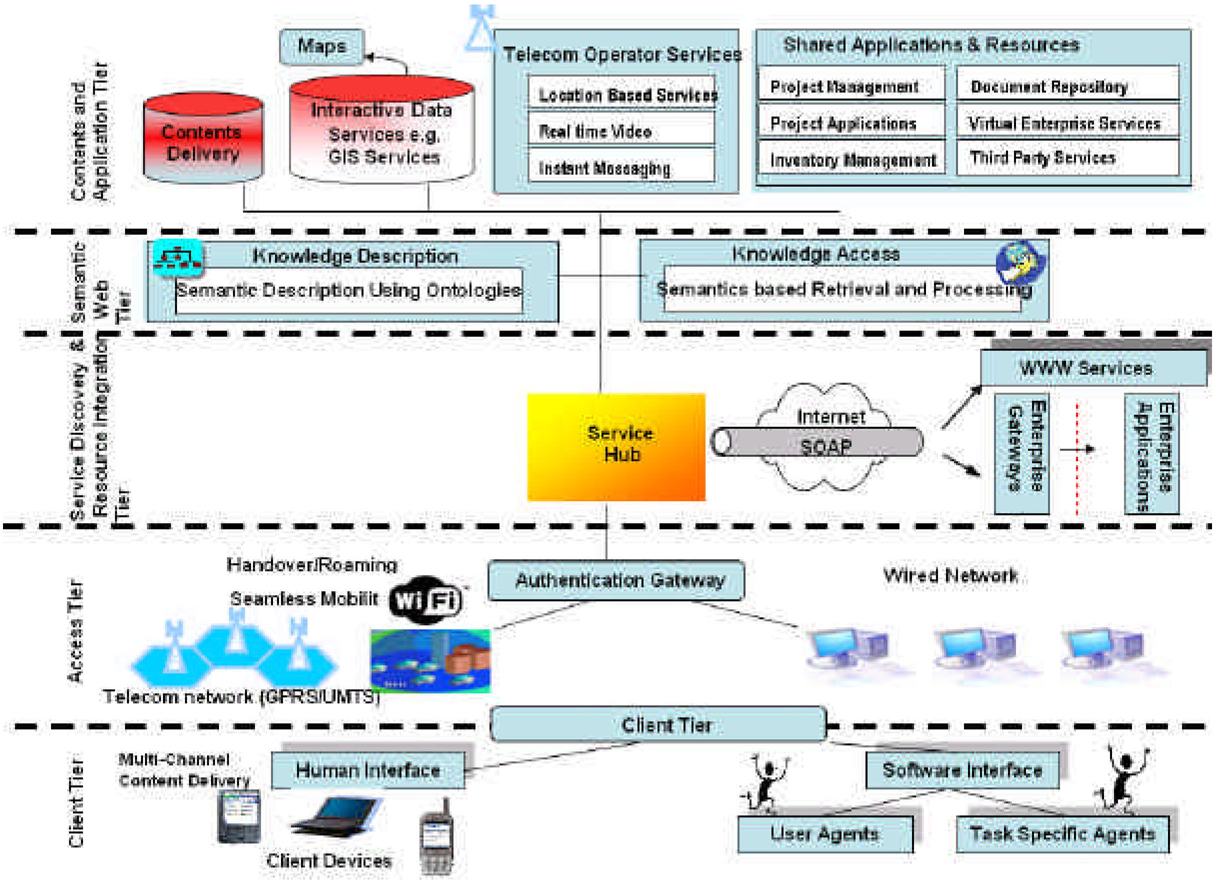

FIG. 3: The Intelligent Remote Collaboration Architecture

The Service Discovery and Resource Integration Tier: This tier will help the construction workers (or their agents) in service discovery. Service hub will use semantic mark-up for resource and service type description. Semantic mark-up will also allow users (or agents) to make intelligent decisions about when and how these resources and services should be used, to solve the problem at hand. Adherence to web services standards will allow applications to share data and dynamically invoke capabilities from other applications in a multi-domain, multi-technology, heterogeneous remote collaboration environment.

The Semantic Tier: This layer will enable knowledge description (using ontologies) and knowledge access (by supporting information retrieval, extraction and processing). Incorporation of semantic technologies in the middleware will reduce the risk of project failure through better visibility and communication. It will also provide mobile workers intelligent access to heterogeneous distributed information, enabling task completion by effective utilisation of available information sources. Use of common ontologies will support inter-agent information transfer.

Contents and Applications Tier: This tier contains mobile collaboration contents and applications. Applications may be provided by project partners or application service providers (ASP). Hosting support may be provided by ASP, project participants, telecom operators etc, depending on the adopted business model.

5. APPLICATION SCENARIOS

This section discusses five scenarios, illustrating the use of semantic web based services architecture in supporting mobile construction workers.

5.1 STANDARD MANUFACTRING COMPONENT SUPPLY

This scenario illustrates the case of a mobile construction worker, generating a purchase order for a standard construction component. The following numbers illustrate the chronology of interaction, and correspond to the numbers in Fig. 4:

1. Using a mobile device, worker first connects to corporate procurement application using a broad band wireless connection, and instructs his Semantic Web agent to search for the approved windows' suppliers. User can disconnect from the network after this stage. In this scenario, the mobile device does not need to support thick client functionality, as the logic and data processing resides on the wired networks and the workload is passed to the user agent on the wired network. This will relieve the mobile device of the time and processor consuming web services related tasks like service discovery and negotiation.
2. A Semantic Web based procurement agent plays the role of mobile worker representative in the fixed network infrastructure. These agents will be intelligent and capable of making decisions on behalf of users.

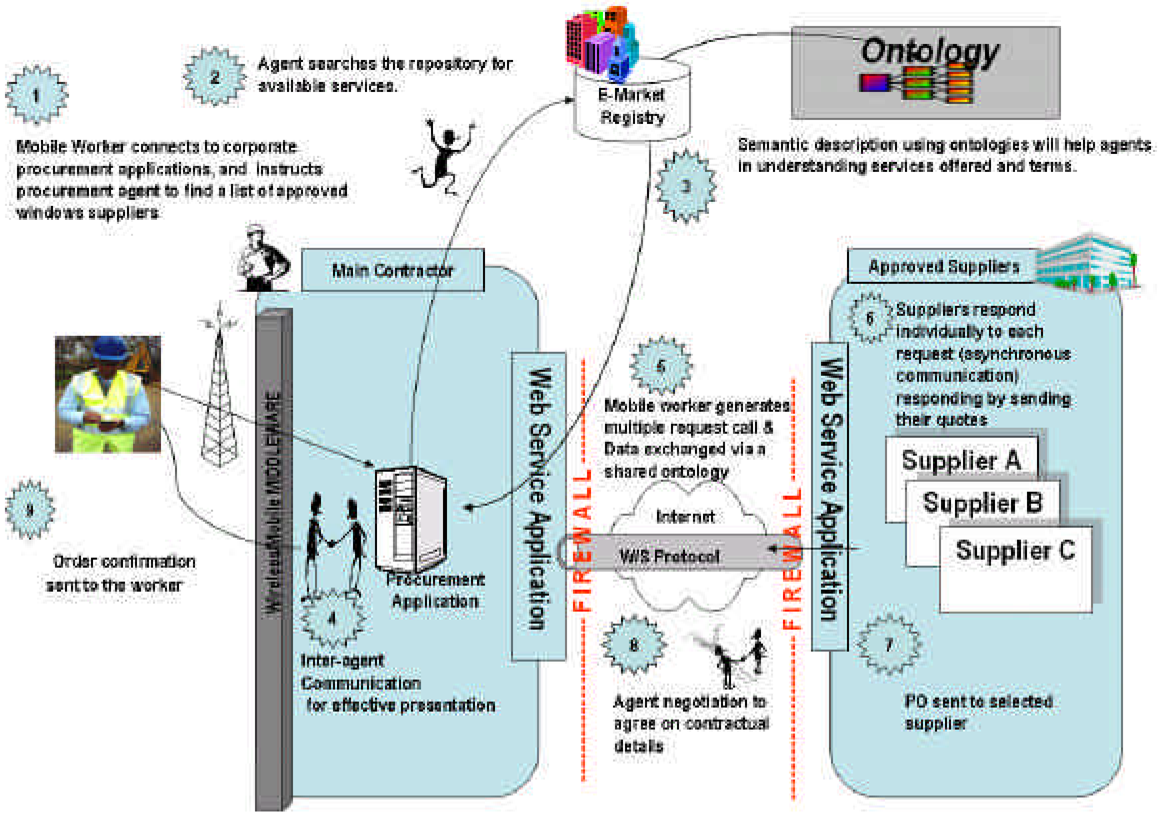

Figure 4: Standard Component Supply Scenarios

1. The procurement agent obtains the information about the component suppliers using a popular construction electronic market registry, which contains a list of approved suppliers. It is envisaged that the trading registry is based on the Semantic Web technologies, which will allow the suppliers to map the data about their products and services into an ontology, used in the marketplace. These ontologies will define the meanings of the terms used in the market place and the rules of data exchange. After mapping, the data will be published through electronic market registries. Such semantic description using ontologies is important, because the service discovery process can

happen only when there is a common language to describe a service in a way that lets other agents "understand" both the function offered and how to take advantage of it (Berners-Lee et al., 2001).

2. List of potential suppliers is then passed from procurement agent to a personalisation agent, which render the information on the workers' device as per user preferences (e.g. language, device type, location, level of detail etc). Such transfer of information between agents is possible using the Semantic Web technologies, which provide the framework for typical processes involving number of agents, in which sub-assemblies of information are passed from one agent to another, each one "adding value" to construct the final product requested by the end user (Berners-Lee et al., 2001).
3. In this scenario, mobile worker decides to make multiple request calls to three approved suppliers to provide their quotes as per the specifications. Data is exchanged between corporate procurement application and suppliers through a shared ontology e.g. aecXML.
4. Suppliers respond individually by sending their quotes. Such communication can either be synchronous or asynchronous.
5. Site engineer evaluates bids from the suppliers. Best quotes are then selected and a purchase order is generated.
6. Workers' agent and the window suppliers' agent negotiate using shared ontologies, and agree on payment of services and other contractual details. Underlying semantics will ensure intelligent inter agent communication/negotiation.
7. An order confirmation is sent back to the buyer, with delivery information. A monitoring agent will monitor the order, ensuring products are delivery by the right date. Any discrepancies are notified to the project manager.

5.2 Project Document Management

This scenario illustrates the case of a typical construction project, which generates an enormous amount of documents e.g. technical drawings, legal contracts, purchase orders, change orders (CO), Request for Information (RFI), permits and schedules, images etc. The application of semantic web services based architecture for handling RFI is discussed. The following numbers correspond to those in the Figure 5:

1. In this scenario, the site engineer wants complete details of a joint in a roof joist drawing. Using a web service client application, mobile construction worker interacts with the project registry, over the wireless network (e.g. WLAN, GPRS/UMTS), to submit a RFI. An audio and video annotation is attached to the RFI, further explaining the nature of the request.
2. RFI is recorded in the project registry. An industry standard (e.g. UDDI) is used to define a construction project data registry. It will act as a shared repository for registering all project related data (project data, inventory data, Drawings, Request for Information, CO etc) and shared applications (available for direct access via web services protocols over the Internet).
3. Semantic annotation using ontologies of all project documents is envisaged in this scenario. These annotations would facilitate indexing and searching. It would also enable improved ways of information submission and retrieval, by describing resources, and links between them. Such semantic description will also enable agents to intelligently synthesise the content from multiple information sources, on ad hoc and on demand basis. Similar approaches on semantic description of resources exist elsewhere, including :

    - ***SCULPTEUR*** (Addis et al.,2003)**,** which aims to create a semantic layer for distributed multi-media information management.
    - ***ARTISTE*** (Artiste, 2003), which developed an image retrieval system, based on meta data.
    - ***MUMMY*** (Mummy, 2003), which employs ontology-based solutions to enable mobile, personalised knowledge management based on the usage of multimedia.
    - ***ANNOTEA (***Koivunen et al., 2003) provide means for users to share communication about Web documents by attaching external annotation metadata to the documents.

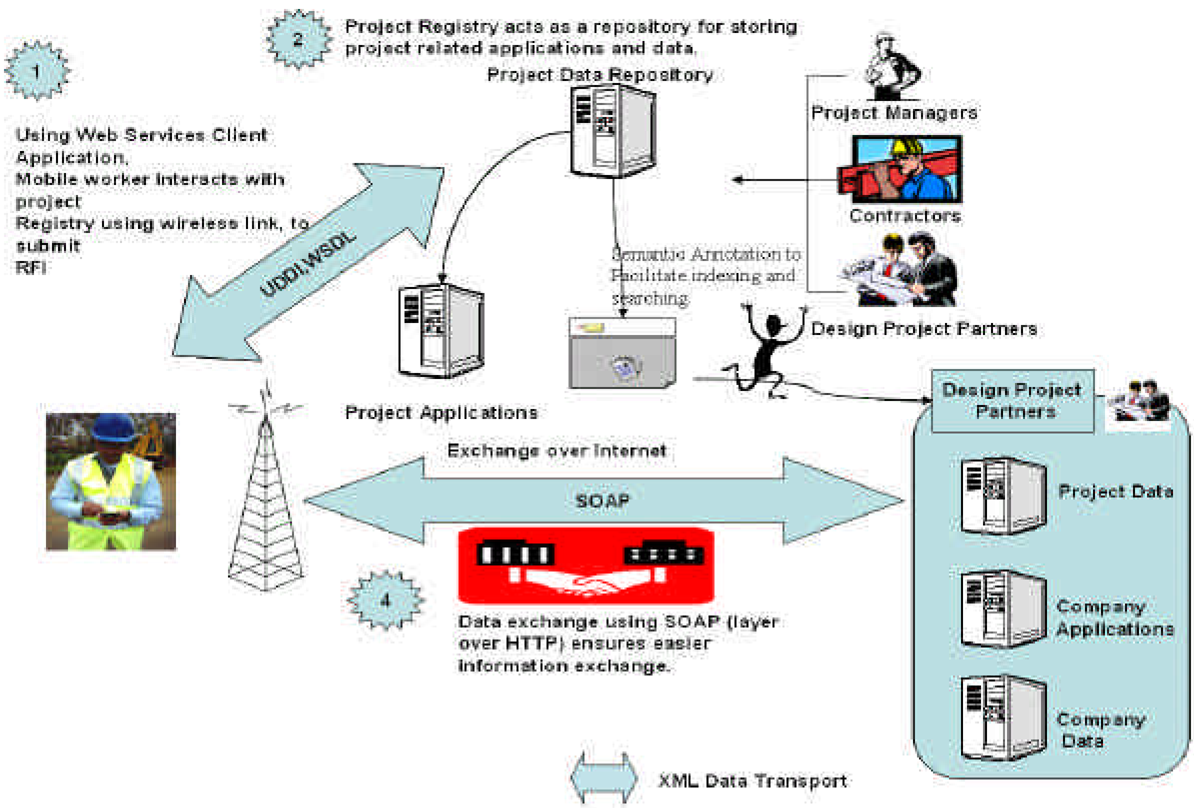

FIG. 5: Project Document Management

4. In this scenario, semantic description of RFI will enable agents to decide, that RFI has to be directed to the design partners. Agent will also help users to track and monitor the RFI throughout its lifecycle.
5. Design partners will take appropriate action on the RFI asynchronously. Completion of RFI is then recorded in project registry. Push based telecom technologies such as SMS (Short Messaging Services) can then be used to update the worker of RFI progress.
6. Using Web Services protocol, the mobile worker then binds to the project servers, to download the latest version of the drawing. Key advantages of semantic web description in this scenario include reduced RFI cycle time, RFI's electronic trail, task automation and quicker searching through semantic annotations.

5.3 THIRD PARTY SERVICES PROVISION

This scenario (Figure 6) illustrates the case of construction application development firm, which has decided to become a service provider , by exposing their engineering application software as a service.

1. An engineering analysis application developer first uploads the application to the application server. In this scenario, application hosting support is provided by a construction industry application's web portal. Using an open standards interface, developers can also monitor user status information etc.
2. Applications can be standalone or can make connections to other web services on the internet e.g. billing services.
3. Application is stored in the server, and entry is updated in the corresponding registry. Registry maintains the list of available applications and description of how to access them.
4. Interested users (wired or wireless) will search the repository to locate available services.

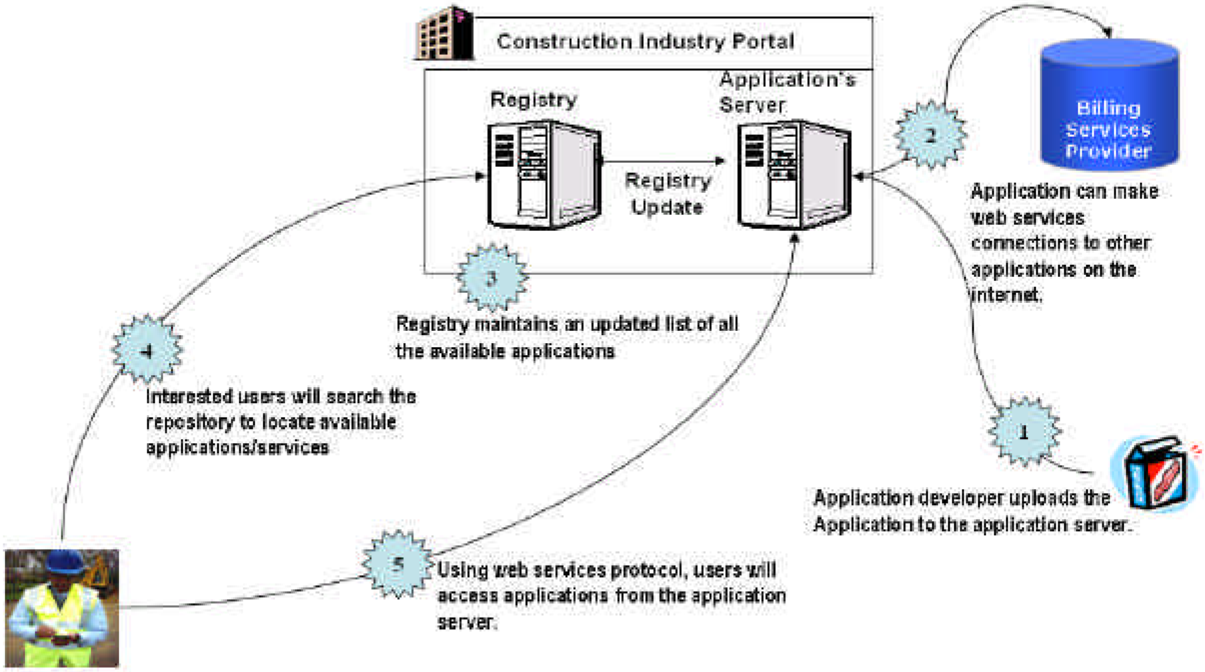

FIG. 6: Third Party Services Provision

5. Using Web Service protocols, users can access applications from the application server. In this case, mobile worker pass parameters for engineering analysis calculations to the application residing on the application servers. Analysis will be done and the user will be sent back the results of the calculation using telecom networks. Separation of logic and data, as envisaged in this scenario charge the clients with minimal memory and processing powers.

5.4 Construction Task Automation

This scenario illustrates the case of the construction task automation, through the automated invocation of the Web Service. Using Web Services architecture, it is possible to implement automated steps into business process workflows. Current initiatives like DAML-S (Ankolekar et al., 2001) are focusing on automated invocation of semantically aware web services. Such invocation can be triggered by a timed event or by an agent, as illustrate in Fig 7.

Main Contractor- Sub Contractor Communication: In this case, main contractor requests project progress, work schedules and deployment of labour report from a sub contractor's project management application at end of the shift, through an programmatically timed process. Business rules will define rules for data exchange. Use of shared ontologies will ensure standardisation of inputs and outputs to project management systems. Using push based technologies, data on project manager's mobile device is synchronised with the servers.

Main Contractor- Concrete Supplier Communication: In this variation of above case, a web service is invoked through an agent. Semantic description of project documents, schedules etc. is envisaged. Such semantic awareness will generate greater visibility and will help agents to generate critical information for the decision support. Here, planning agent have noted a time lag of one day in the project schedule. Agent invokes the web service of concrete supplier, notifying the suppliers agent of the delay, and renegotiating new date, time and terms of service. It is assumed that main contractor and suppliers' data is available in a machine processable format, which would allow intelligent agent communication. Project manager can then be updated of the new schedule using push based technologies e.g. SMS.

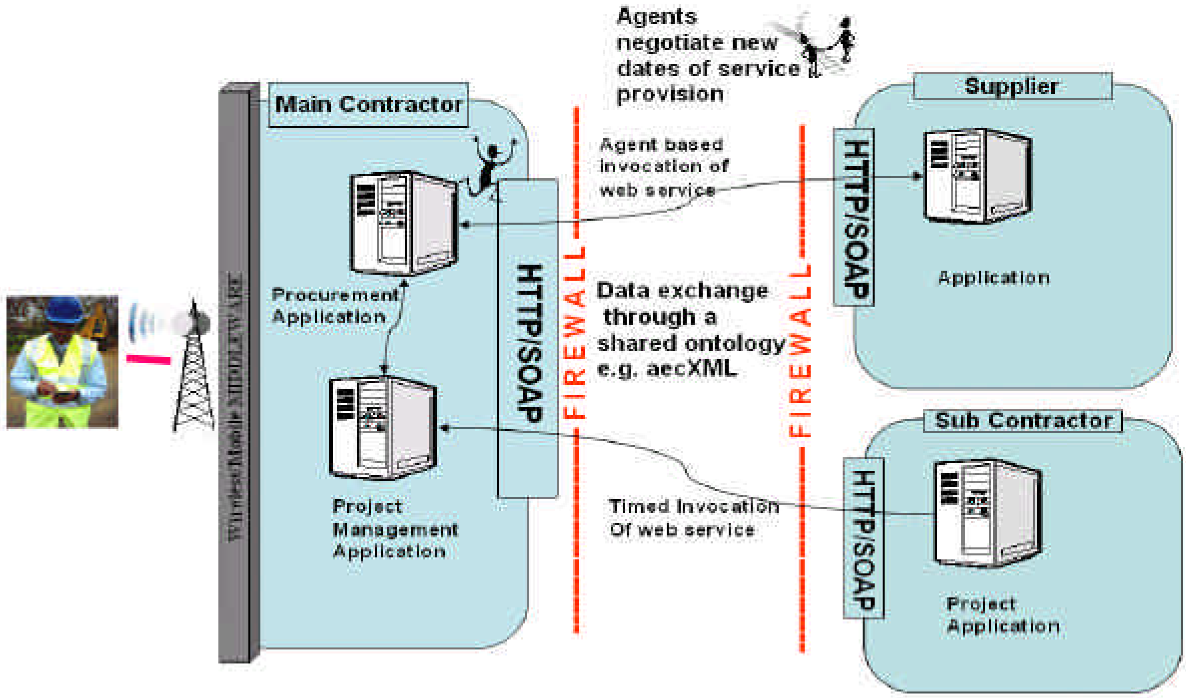

FIG. 7: Construction Task Automation

5.5 Ubiquitous Computing

Although many construction collaboration applications make extensive use of virtual project environments, in reality a significant working time of the construction workers is spent on activities in the physical environment. Ubiquitous computing technologies have the potential to make collaborative processes and services sensitive to the data available in the physical world (Anumba, 2004). Ubiquitous computing, a term originally coined by Weiser (1991), refers to proliferation of computing capabilities into everyday objects. Adler (2003) identified three key advantages of Semantic Web technologies in the realm of ubiquitous computing :

- Semantic Web enables individual addresses for everything (using URI). URI can point to anything in the physical world, including RFID tags, Sensors, cameras, wearable computing devices etc. Such ubiquitous computing devices can advertise their functionality- what they can do and how they are controlled- much like software agents. RDF based Capability/Preference Profile (CC/PP,2003) standard helps in describing functional capabilities of devices and user preferences. By adding languages for handling ontologies and logic, devices could automatically seek out and employ services and other devices for added functionality, enabling automation with minimal human intervention (Berners-Lee et al, 2001). This will enable multi-device capability through the specification of any web resource
- Explicit representation of device capabilities and service functionality: Currently available service discovery and capability description mechanisms include Sun Microsystems's Jini (Service Focused) and Microsoft Universal Plug and Play (device focused). They describe the mechanism through which functions offered by various ubiquitous computing devices are described, advertised and discovered by others.
- Semantic Web as the basis for "semantic interoperability".

In recent years, many researchers have focused on the application of semantic web technologies in the realm of ubiquitous computing (e.g. Lasilla et al., 2003, Sashima et al., 2002). Different ubiquitous computing application scenarios for on-site work include context sensitive information provision on site, materials management, on-site data capture, remote monitoring etc.

6. SUMMARY AND OUTLOOK

With the emergence of high speed wireless networks, such as Wi-Fi , 802.11 and 3G, Semantic Web Services emerge as the answer to efficiently provide intelligent mobile collaboration support to mobile construction workers. An architecture is discussed in this paper, which enables a pervasive, user-centred mobile work environment by bringing together necessary technology threads including Semantic Web, Web Services and Agent technologies. Collectively, these technologies open up new possibilities for leveraging the capabilities of mobile computing in the construction, where the Semantic Web supports contextual meaning enabling user in task accomplishment and Web services technologies allow registration and discovery of services based on the worker context. Collectivity of these technologies has the potential to cause a paradigm shift in construction management practices by allowing mobile worker access to a wide range of data and services on as-needed basis. However, realisation of the real potential of semantic web based services for mobile computing in the construction industry needs to satisfy the constraints introduced by technological complexity, cost, user needs and interoperability. At the same time, at the level of an individual construction firm, it often takes more than technology to determine whether or not, returns on innovation investments are always positive. For an average construction contractor, a wireless workforce project is still a journey into an unknown territory, often in partnership with various untested mobile infrastructure providers. Thus, there is a need for successful industrial case studies. Our next step is to build a prototype, in collaboration with our industrial partners. Prototype will demonstrate the concepts presented in this paper.

7. ACKNOWLEDGEMENT

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