MOTIVATING ENGINEERING/BUSINESS PROBLEM

The AEC supply chain is fragmented in the same way as most information management processes in the industry are. An integrated supply chain would include activities from design, procurement to installation, performed by different parties and organizations. As the current practice indicates, having information available as needed can significantly reduce lead-time as well as increase accountability for tracking purpose. Sharing of information within and across companies is critical in effective supply chain management [Lee 2000]. However, this is not an easy task: the information sources are often scattered in several locations, utilizing different software and hardware platforms and not easily accessible. Information gathering takes too long; no single individual can handle all of information in a supply chain because one has to deal with many products, numerous requirements, and many types of transactions. Another difficulty in sharing information is the nature of the AEC business: "One-of-a-kind nature of project, temporary multi-organization". Specifying proprietary-designed representations and "one-time" information channel to exchange data and knowledge is not viable or justifiable. In addition, different goals and objectives of project participants deter information sharing. If these difficulties can be overcome, there is a lot to be gained in the AEC industry.

The purpose of interoperation is to increase the value of information when information from multiple and, likely, heterogeneous sources is accessed, related and combined. Specifically, interoperability allows two or more information sources (which could be computer systems or software components) to exchange information and to re-use the information for further purposes. Interoperation thus provides added value to each individual source and, in particular, enhance efficiency and productivity in a supply chain. A study by NIST has shown that inefficient interoperability costs more than $15.8 billion, in the year 2002 alone, to the construction industry on the design, construction and maintenance of large commercial, institutional and industrial buildings (not including public works and other civil infrastructures systems!) [Gallaher et.al. 2004]. An earlier study performed by NIST Strategic Planning and Economic Assessment Office conservatively estimates the economic cost due to lack of interoperability in the United States automotive supply chain alone at one billion dollars per year [NIST 1999]. In today's economy, companies around the world are trying to take advantage of the information and communication technologies (ICT) to create virtual supply chains where customers, suppliers, and business partners collaborate with each other. Nevertheless, effective use of ICT for information sharing among participants in a supply chain poses a significant challenge in the AEC industry.

This seed research proposal is to initiate a study to create a framework that can coordinate distributed, semantic-rich engineering services in order to solve the fundamental interoperability problems faced by the AEC industry and to support workflow and supply chain applications. Our focus will be on the issues of information and process integration and two significant services will be produced – (1) mediation of heterogeneous information sources to "harmonize" different ontological standards so as to support an integrated service environment; (2) software framework for service composition through which connectivity and interoperability among software applications can be achieved.

THEORETICAL AND PRACTICAL POINT OF DEPARTURE

Supply chain management (SCM) tools[1] exist, although most of them focus their applications in the manufacturing industry, to help managers to deal with project management tasks (such as decision support (event management), inventory management, order management, production, scheduling, demand planning/forecasting, supply planning, distribution planning, transportation management, warehouse management, etc.), but they rarely include upstream design and

[1] Examples include i2 Technologies Inc., www.i2.com, SAP Inc., www.sap.com , and many others.

downstream operational activities. From the AEC industry perspective, however, it is not obvious how these applications are even suitable since these tools are targeted for large manufacturers and retailers which have relatively stable supply chains. Furthermore, implementation and configuration of these SCM tools are complex and take time. The AEC industry has project-based temporary supply chains: that is, its supply chains keep changing from project to project in most cases and cannot afford to spend much time in configuring a system. Therefore, an application for this industry has to be flexible enough to accommodate a different supply chain efficiently. Effective and flexible information sharing and service integration is therefore required for supporting supply chain activities in the AEC industry.

Information Interoperability

The need for efficient information exchange in engineering has been a subject of active research and development since the mid 1980s. Probably, among the most recognized industrial exchange standards is the ISO's STEP effort [ISO 1989]. Within the AEC industry, there have been many product models such as CIS/2 for the steel industry [Coleman and Jun 2005], PlantSTEP and AEX for the process plant industry [Palmer 2005] and the IAI's IFC (Industry Foundation Classes) for the building and construction industry [IAI 1997]. While the earlier models focus primarily on product description data, recent developments have also incorporated data definitions for cost estimation, project management and supply chain [Danso-Amoako et al 2004, Begley et al 2005]. As opposed to the manufacturing industry where product model standards have become common practice in product lifecycle management (PLM), the AEC industry has just started to realize the importance of information sharing and exchange [Coleman and Jun 2005, Palmer 2005].

Service Integration and Interoperation

With the rapid development of the Internet and networking technologies, the computing environment is evolving toward an interconnected web of autonomous services, both inside and outside of enterprise boundaries. A "web service" can be described as a specific function that is delivered over the Internet to provide a service or information to users. Web service integration is important for the automation of application-to-application or organization-to-organization cooperation using the Internet infrastructure. However, it is not easy for a user to perform a complex task which composes of many sub-tasks and requires access to many web services.

To integrate distributed services over the Web, not only information interoperability standards need to be employed, so that results can be reused by other applications, network communication and mechanisms for invoking and terminating applications over the network have to be provided. With the emergence of Web-based software applications, many languages have been proposed to facilitate the reuse of Web services or software components. Examples include Web Services Description Language (WSDL) [Booth and Liu 2004] and Flow Language (WSFL) [Leymann 2001], Business Process Execution Language for Web Services (BPEL4WS) [Andrews et al. 2003], and Web Service Ontology based on DARPA Agent Markup Language (DAML-S) [Ankolekar et al. 2001]. Recently, semantic web services modeling language such as WSML [Bruijn et al. 2005] have been proposed to promote the use of semantic reasoning about services. These service description languages, however, are mainly targeted for business oriented applications and are not designed for managing and reusing information to support engineering applications. For example, the AEC industry typically employs stand-alone applications (e.g., Microsoft Project, Microsoft Excel, Primavera Project Planner, and AutoCAD) that are designed for specific application and generate large volumes of information that are not easily shared among applications. Even with many existing online Web services, such as weather forecasting, product catalogues, finance reports, etc., these services are not readily integrated with traditional standalone applications.

METHODS

With the proliferation of Internet and communication technologies, the exchange of information is essentially free and instantaneous. However, in order to support meaningful exchange of information among software applications and to bring them working together to solve a complex, business problem, software applications must be able to convey and understand the semantics among each other. Current developments of interoperability standards, although they do provide the means of communication among the tools within a narrowly defined domain, do not resolve the complex interoperability issues in a supply chain, which typically involves information and service integration across multiple disciplines, each has its own terminologies and its mode of operations. This seed research proposal intends to develop methodologies and tools to identify the semantic similarities and differences among the standards and support integration of loosely coupled, distributed engineering services. The research consists of two basic work packages:

- Introduce a knowledge driven approach to enhance analysis and manipulations of information from heterogeneous sources.
- Develop an integration framework to specify and compose distributed engineering services.

The objective is to support information sharing and service integration needed for an AEC supply chain environment.

A Knowledge-Driven Mediation Approach for Information Analysis

As discussed earlier, ontologies have been increasingly used to describe terminology used in information sources. Ontologies provide a terminological basis for information exchange among a community of interest and serve as a means for knowledge sharing and reuse. In engineering, there have been many attempts to build a single, unifying model of concepts and definitions in the hope of tying together different automated systems. Such a model, however, will never be practical [Ray 2002]. In order to manage and to handle the increasing web of ontologies, it is important to transform the information sources from the perspectives of the distinct ontological standards into the context of the users and their applications [Wiederhold 1994]. As an example, migration of data from one version to another version of a standard model (e.g. IFC) can pose significant problem simply due to renaming of classes and terms (not to mention possible changes in their structure). Tools are needed for the extraction of terms and "harmonizing" ontologies. Formal operations are necessary for the articulation of overlapping ontologies (as depicted in Fig. 1).

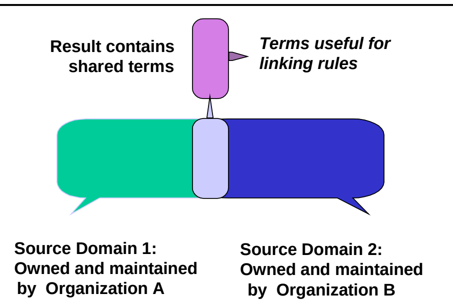

Fig. 1: Intersection operation to define articulation between two sources

Mediation has been shown to be a useful means to resolve problems of semantic differences among different information formats. In the proposed approach, metadata are defined or extracted from each information source; the metadata is then a used to map the information and knowledge among different information sources. To construct the needed metadata, advanced text and data mining methodologies can be deployed to analyze and compare the information sources, thus creating rules that can enable articulation, linking disjoint information resources, and interoperation. Articulated knowledge is then used to join data repositories and knowledge bases with different structure and semantics. Fig. 2 illustrates an example application in extracting similar terms and their semantic relationships using the knowledge about the two information sources, in this case UFAS [1997] and BS8300 [2001] regulations on accessibility [Lau et. al. 2003]. By exploring the document content and its structures, we resolve the terminological differences ("door hardware" versus "door furniture"); a simple concept or term comparison, cannot identify the match between them. In short, we propose an innovative, knowledge-driven approach, through advanced computational methodologies, to resolve ontological concepts and representations, and thus enable semantic information interoperability among heterogeneous applications and standards.

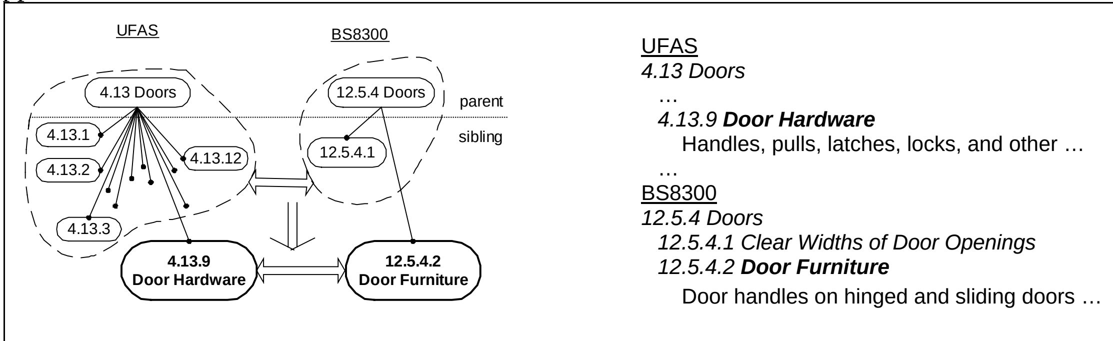

Fig. 2: Similarity Analysis between American and British Regulations [Lau et.al 2003]

Service Composition

While information integration is based on shared interests among applications that require semantic mapping, integration of services is essential to support business or engineering processes. This level of interoperability requires not only the metadata schema (such as a product data or model exchange standards) but also the modeling of the processes that form a workflow or a supply chain. This level of integration is the province of semantic web services and deals with semantic interoperation of application services [Preist 2004]. The core concept of service integration is the connectivity and interoperability among software components that work together on a specific task or process. While various web service models have been proposed, there is a need for a software framework that includes the necessary mechanisms for integrating distributed engineering and business services, a simple language for specifying the process scenario and the ability to query and visualize results from multiple tools and applications. Our research effort will focus on a web service integration infrastructure that separates execution controls of services and data flow streams as a means to enhance performance and scalability for large scale engineering services which typically involve very large data sets. Furthermore, a simulation language and access mechanisms will be developed to allow users to compose web services and query simulated results. The following two scenarios illustrate the potential of a web-based distributed environment for workflow and procurement services.

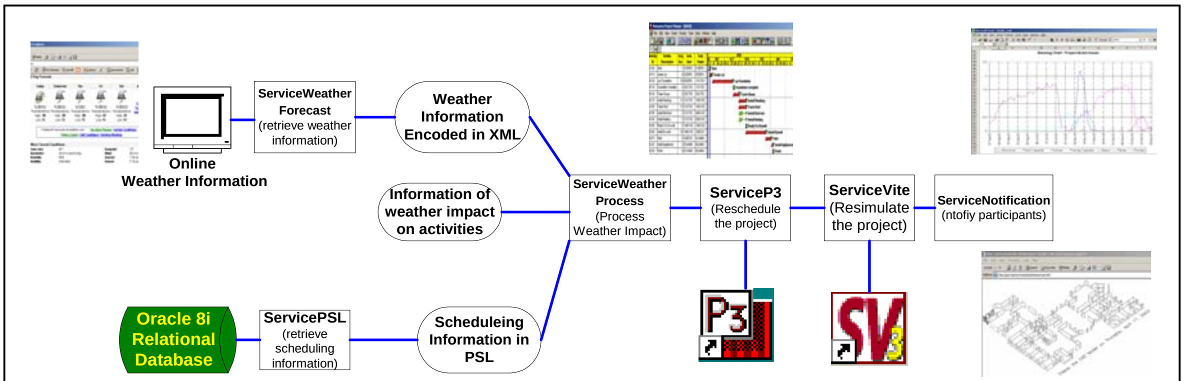

Fig. 3: Integrating Online (Weather) Service to Engineering Simulation

Fig. 3 shows an scenario workflow example to illustrate bringing an on-line service to engineering simulation. Here, the weather forecast information is dynamically downloaded from the web. The information is then integrated with project information (expressed in PSL, an ISO standards for process language [Gruninger and Menzel 2003]). The impacts of the weather conditions to the schedules and resources are simulated using Primavera P3 and Vite SimVision. The results can be queried and displayed to interested parties as charts using Microsoft Excel and web browser on any desktop.

As another example, Fig. 4 shows the possibility of dynamically downloading product information (from online catalog or suppliers' database) into a design and creating a procurement list (that can further be used for further product comparison and inventory management). In this example, Autodesk's i-drop technology (see http://www.autodesk.com/idrop) is employed to drag-and-drop product description into a design. Manufacturing information such as model code, manufacturer, supplier, price quote, etc. are also attached as object attributes such that a procurement list (and cost estimation) can be produced during design.

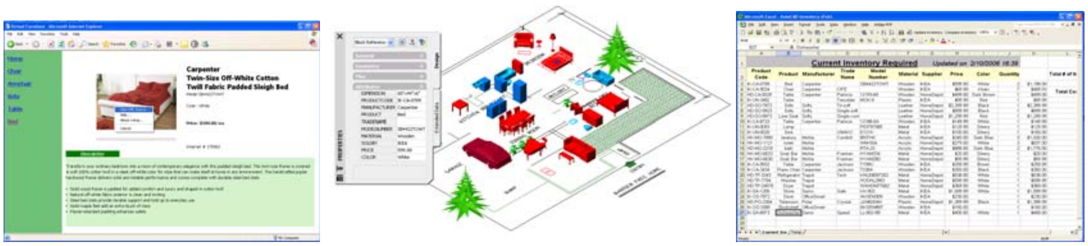

Fig. 4: Integrating Online Catalog with CAD and Inventory

A "virtual" supply chain is a vital element of today's business environment. Companies around the world are trying to take advantage of the Internet and information technologies to create virtual supply chains where customers, suppliers, and business partners can collaborate with each other. The examples above illustrate the potential applications of information interoperability and service integration in virtual design and workflow simulation and procurement process. To further enable dynamic supply chain environment, the tools and methodologies need also support an organization to keep track of information and to monitor key data, such as inventory level, order and delivery status. Furthermore, project participants can gather information with schedule data so that they can forecast potential problems. If problem arises, others across the chain can quickly be informed so that new services and strategies can be deployed to resolve issues at hand. This proposed seed research project will produce a framework that can demonstrate these functions and activities.

RELATIONSHIP TO CIFE GOALS

This research focuses on information interoperability and services integration. This proposed research touches upon at least five of the CIFE research areas and goals:

Engineering modeling methods:

- Modeling of product, process and organization data for information exchange and sharing purpose.

Analysis methods:

- Establishment of integrated megaservice framework to invoke, simulate and update schedules, resources allocation, cost estimation and to facilitate procurement process.
- Incorporation of web-based application services with online information into engineering simulation

Business metrics:

- Support for information flow and global supply chain.

Strategic management:

- Integration of loosely coupled and distributed information and services for strategic decision-making.

Economic Impact analysis:

- Cost saving due to efficient interoperation among heterogeneous applications, leading to reduced inventory, improved customer service and increased corporation transparency and accountability.

INDUSTRY INVOLVEMENT

We expect that our work will be of interest to many organizations from industry and government agencies. We have identified Professor Arto Kiviniemi of VTT Technical Research Centre of Finland who has agreed to be a collaborative partner in this seed research project. Specifically, this proposed topic will be related to the ISCIS – Integrated Supply Chain Information Systems project at VTT and Chalmers (Prof. Hans Bjornsson). We will also collaborate closely with Dr. Kent Reed (on IAI's ifc and CIS/2 Interoperability project) and Dr. Mark Palmer (on FIATECH's AEX Interoperability project) in NIST's Building Integrated Building Process Group and with Dr. Ram Sriram of the Manufacturing Systems Integration Divisions. NIST has identified information interoperability and supply chain management as one of the key initiatives. Additionally, we will work closely with Mr. Dave Conover of the International Code Council towards the development of next generation "smart" code (a Building Smart Initiative) which will further enhance interoperability between building codes and models. (Prof. Law has been the only academic participant in this "smart" code initiative so far.) We expect such collaboration will be particularly fruitful in establishing synergistic research activities towards improving the development of interoperability standards for the AEC industry. Our plan will include presenting our results and findings at FIATECH's workshops to solicit feedback and suggestions towards the end of the first year seed project period. Last but not least, we anticipate feedbacks and participations from facility managers and owners, government agencies and CIFE company members.

RESEARCH PLAN, SCHEDULE AND RISKS

Organization and key personnel

This proposed interdisciplinary research involves investigators from Civil and Facility Engineering (Prof. Kincho Law and Dr. Chuck Han) and Computer Science (Prof. Gio Wiederhold). Prof. Wiederhold has been involved in information science research for over 40 years and has long envisioned the important role of mediation for information systems [Wiederhold 1992] and web services [Wiederhold 2005]. Dr. Chuck Han (Consulting Assistant Professor) is an expert in ICT research and practice in CAD and facility engineering. Prof. Law has been actively involved in engineering information management and enterprise integration for over 20 years. The research team will also be assisted by an assistant, Mr. Jack Cheng, whose PhD research focuses on ICT in Supply Chain Management. Researchers from VTT, Chalmers and NIST will also be participating in this research project.

Research Tasks, Schedule and Milestone

We anticipate the following results from the proposed research:

- By the end of Autumn Quarter – We plan to define and develop methodologies for the mediation tools, and the service integration infrastructure.
- By the end of Winter Quarter – We plan to implement and test the basic framework with a simple procurement supply chain applications (as illustrated in Fig. 5).
- By the end of Spring Quarter – We plan to define and scope a series of case scenarios with increasing complexity jointly with international collaborators, as well as research and industry partners .
- By the end of Summer Quarter – We plan to select a set of case scenarios of modest scale (a building project with 3-5 disciplinary teams) to demonstrate the methodology and solicit feedback from internal and external use.

Validation and calibration of the information system will be an ongoing activity, which we do not expect to complete by the end of the project calendar year. The purpose is to identify the needs and formulate the theoretical framework for this first year seed project. Further research tasks will be the focus of subsequent years (with the expectation of funding from outside sources).

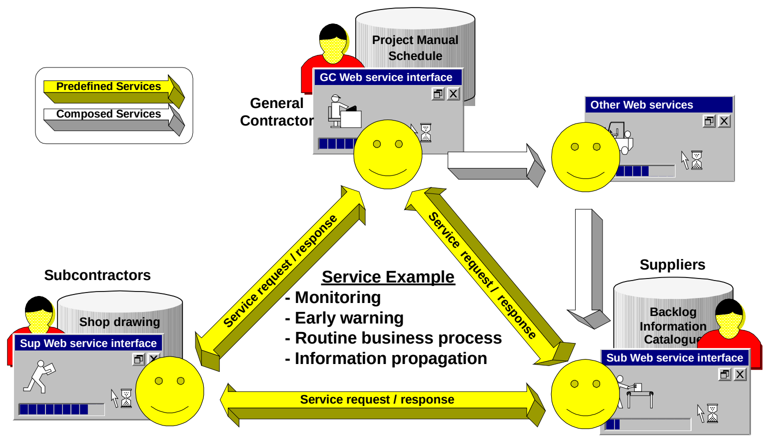

Fig. 5: A Proposed Testbed Application Scenario

Risks

We recognize that to establish a comprehensive information system infrastructure to support the full web service integration of a construction supply chain is a task beyond a 1- or 2-year seed research project. However, pilot projects such as the one proposed here represents a feasible objective that can lead to fundamental understanding of the research and development effort needed for broader implementations. We also realize that wrapping existing software applications into autonomous services and integrating these tools can be challenging. Some of the issues have partially been addressed in prior works [Liu 2003, Cheng 2004]. In addition, we plan to leverage the collaborations with other researchers and their organization to maximize the output of this proposed research. This research will address some critical interoperability questions faced in our industry: What types of interface standards, modeling tools, and test methods will be needed to capture and exchange the semantics in construction supply chain? What types of standards, tools and methods are needed to deal with today's and tomorrow's technology? Which emerging standards and methodologies will provide the needed functionality for new advanced applications? We firmly believe this proposed seed research will contribute to these critical issues. The collaboration among the researchers from the different background and expertise will help achieve our objectives and goals.

NEXT STEPS

We plan to continue this research by exploring government funding opportunities such as the National Science Foundation, NIST and others. As noted, NIST (as well as FIATECH) has identified information interoperability and supply chain management as one of the key initiatives in their organization and has proposed for significant funding and supports in this area. We have collaborated with and received funding from NIST in the past. With initial results from this proposed seed research project, we anticipate further funding supports from NIST as well as from NSF on this critical problem. This proposed research represents a critical area for ICT in the global construction and enterprise integration. We will also search for further collaborative and funding opportunities with international partners.

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