Theme:

Title: **Developing Message-Based Interoperability Protocols for Distributed AEC/FM Systems**

Author(s): Mahmoud R. Halfawy, Arezou Pouria, and Thomas Froese
Institution(s): University of British Columbia, Canada
E-mail(s): halfawy@civil.ubc.ca, apouria@civil.ubc.ca, tfroese@civil.ubc.ca

Abstract: *This paper discusses the requirements and a methodology for developing, implementing, and possibly standardizing, an extensible set of common message-based protocols for exchanging project-specific and industry-wide information based on the IFC data model. The protocols define the syntax and semantics of various data exchange messages in the context of AEC/FM projects. The interoperability protocols will achieve two goals: enabling project roles and applications to exchange information in a consistent and standard manner; and enabling the full or partial automation of a set of project workflow processes. The protocols aim to enable heterogeneous and distributed AEC/FM systems to exchange information, within or across organizational boundaries, across all project phases. Interoperability protocols would include transactions for requesting or querying information from various data sources, exchanging design or construction data related to a specific project, exchanging data related to a specific business transaction (e.g. purchase orders), distributing updated project information to project teams, or requesting the execution of specific operations. Formalization and standardization of data exchange protocols between various project roles and applications will potentially provide better communication, increased quality, productivity, and reduced costs, delays, and contractual disputes.*

Keywords: *Interoperability protocols, transactions standards, IFC*

Introduction

The Architectural, Engineering, Construction, and Facility Management (AEC/FM) industry is inherently fragmented, project-oriented, and multi-disciplinary. AEC/FM projects are typically accomplished by a collaborative effort of several organizations that operate in a “virtual enterprise” to accomplish the project. For the duration of the project, geographically and temporally distributed project partners need to share and exchange an enormous amount of information. Coordination of the project activities depends to a large extent on the ability to exchange information among project parties in a consistent and timely manner. Inefficient communication of information has often resulted in project cost and time overruns, reduced quality and productivity, rework, loss of design intent, and the inability to efficiently access and communicate project information in a timely fashion. Moreover, emerging industry trends for globalization, outsourcing, and partnering combined with the increasing pressure to reduce projects time and cost and improving quality and productivity make it even more critical to enable project teams and software applications to exchange project information in an efficient and effective manner.

Project information is typically represented in the form of “unstructured” documents that are exchanged in an informal and ad-hoc manner. Given the complexity and size of information and the number of participants in a typical project, the difficulty to formalize, structure, and organize the project information flow becomes apparent. Experience shows that a significant amount of project time and resources are spent to access, search, and exchange information.

Although electronic communication has been in use in several industries for almost two decades, and despite of the promise that this technology holds to improve many of the AEC/FM processes, the industry has yet to employ and realize the benefits of this technology. Also, despite the fact that the vast majority of the AEC/FM organizations are using the Internet and that the number and sophistication of software tools are steadily increasing, little impact or benefit has been realized with regard to the overall project processes, productivity, efficiency, and cost and time savings. The inability to leverage the use of the Internet or, generally, IT in the industry can be primarily attributed to the lack of standard and consistent protocols to represent and exchange project information. Lack of transactions standards in the AEC industry was a major impediment for the adoption of electronic communication technologies and leveraging the use of the Internet in the industry.

Currently, transactions in the AEC industry, even when standard data models are used, are primarily person-to-person or person-to-application transactions that are conducted in a form that is agreed upon by the communicating parties or dictated by the application. Transaction examples include: requesting product or schedule data, submitting a change order, electronic tendering and procurement, materials management, resource scheduling, and site information. Standardization of the transactions will potentially provide better communication, increased quality, productivity, and reduced costs, delays, and contractual disputes and litigation. These standards would further enable AEC software tools to interoperate in heterogeneous and distributed environments within or across organizational boundaries in a flexible and extensible manner.

Recently, many AEC organizations started to use web-enabled software tools, project web portals, and B2B e-commerce transactions. Although these systems enabled better collaboration and information exchange between project teams, and enabled organizations to perform some business processes online, the information is still exchanged in an unstructured ad-hoc format and in a manual and informal manner. These systems lack a consistent framework that define their operation and transactions, and generally do not interoperate with other systems. With the expected proliferation of these systems, the need to formalize and standardize protocols to enable their interoperability becomes even more critical. Also, the emergence of industry-wide data repositories such as product catalogs and online libraries has increased the demand to develop common transaction interfaces to enable easy access to these repositories over the Internet. The need to have systems interoperate and share project data across organizational boundaries, where sharing a common database is not possible, increased the need for developing such protocols.

This paper discusses a methodology to develop and implement an extensible set of common protocols that can be used to exchange AEC information based on the IFC data model. The main idea is to enable various applications to communicate using the XML schema of the IFC model to exchange project information or to access libraries and data sources. The goal of this research is to develop transaction-based protocols to enable distributed and heterogeneous AEC/FM systems running within or across organizational boundaries to exchange information in a standard message-based manner. Implementing these protocols would require: specification of project-specific and industry-wide data exchange requirements; specification of workflow and transactions context; and specification of the types of information that are involved in each transaction. The interoperability protocols will primarily achieve two goals: enabling applications to exchange information in a consistent and standard manner; and to enable the full or partial automation of some project workflow processes.

Related Work

Electronic Data Interchange (EDI) standards and tools (Pfeiffer 1992) have been around for about two decades. Organizations have used EDI to support their data processing tasks and to automate the exchange of data across their organizational boundaries in the form of standard transactions. (Almeido et al, 98) reported that there are 28 generic EDI messages that can be used in the construction industry, 12 of which were developed specifically for the construction industry. These messages mainly cover tendering, establishment of contract, materials management, accounting, and drawing administration. In spite of the many research efforts that have been conducted during the past several years to introduce EDI to the construction industry, very limited success has been achieved (Almeido et al, 98). Traditionally, the cost of proprietary EDI software and hardware needed made it infeasible to many AEC/FM organizations to implement and maintain EDI systems. Moreover, the lack of an industry-wide standard project information model (e.g. IFC) caused EDI applications to be limited to address project processes related to procurement and tendering. However, the emergence of web-based standards, and the many ongoing efforts to base EDI systems on XML (e.g. EDI/XML, 2002) as well as the availability of the standard IFC data model, are expected to change this picture in the near future.

A large number of initiatives have been launched to study the development of standard web-based protocols to enable B2B information exchange. Many of these initiatives have adopted XML as the language of communication and defined a number of business protocols. Given the generic scope of these business protocols (e.g. procurement), some of them could be readily applicable to AEC/FM projects. However, more AEC/FM specific protocols that address the exchange of project information (e.g. product and schedule data) still need to be developed. Most notable among these initiatives are ebXML, cXML, eCo, and RosettaNet.

The Electronic Business using XML (ebXML, 2002) is a B2B protocol specification that aims to develop standard specifications for interoperable and secure B2B e-business protocols to exchange business data in the form of messages, define common data dictionaries, and to define and register business processes.

Commerce XML (cXML, 2002) is another protocol standard for communication of data related to electronic commerce. The specifications address both protocol interactions and business documents contained in the transactions.

The e-commerce Framework project (eCo, 2002) defines an architecture and a set of semantic recommendations to allow businesses to discover each other on the Internet and to determine how to conduct business with each other. eCo framework supports the integration of three e-commerce services: semantic integration of multiple database types with multiple data constructs and data libraries, trusted open registries, and agent mediated buying.

RosettaNet (RosettaNet 2002) is another initiative that aims at developing XML-based business interfaces for the electronics industry. RosettaNet defines three layers of standards: Partner Interface Processes (PIPs), to formalize the characteristics and requirements for specific transactions between parties; Dictionaries, to define the properties of the products, partners and business transactions; and Implementation frameworks, to specify data exchange implementation details.

Many research projects have studied message-based communication between AEC/FM systems. However, few of these studies addressed the formalization and standardization of the message-based transactions. In a previous project (Halfawy, 98), we implemented an agent-based distributed software system, using the RPC-based Parallel Virtual Machine (PVM) message-passing library, to support message-based communication between structural design and construction planning software systems over a heterogeneous network of Windows NT and UNIX workstations. The need for developing a high-level consistent way to specify and communicate these messages became evident during our attempt to integrate more software tools into the system and to generalize the message structures. (Khedro 1995) discussed a distributed system to facilitate design and construction integration through cooperative network communications. The system supported messaging using domain-specific ontologies represented in the Knowledge Interchange Format (KIF) and used the Knowledge Query and Manipulation Language (KQML) to exchange messages via facilitation services. (Whitby and McWilliams 2000) studied the exchange of information between the design office and steelwork fabrication using EDI. The Construction Industry Trading Electronically (CITE, 2002) project is another initiative to develop XML-based protocols and tools to support project aspects such as electronic tendering, product data exchange, reinforced bar schedule exchange, among others. The aecXML effort (aecXML, 2002) aims to develop standard XML schemas for different AEC project information including resources (e.g. project documents, materials, parts, etc.) and activities (e.g. design, estimating, scheduling, construction, etc.).

Supporting AEC/FM Systems Interoperability via IFC-Based Messaging Protocols

Much of the research throughout the last decade was driven by the need to develop standard industry-wide data models to support systems interoperability and efficient data exchange. The IFC model is the culmination of over a decade of research and development. The model has undergone four major releases, and many commercial software tools have already implemented IFC file exchange capabilities. The IFC model defines an integrated schema to represent the structure and organization of project data, to integrate the multi-disciplinary project aspects, and to facilitate the exchange of project information between function-specific software tools. The model represents the core project information including building elements, geometry and material properties, project costs, schedules, documents, and organizations.

In the simplest form of interoperability, the project model is communicated from one software package to another in a data file (e.g. using ISO 10303 Part 21 format). Upon receipt of the data file, the software will re-create the project model for further processing. Also, the IFC data model enabled systems to exchange project information through the use of a centralized database. However, there are some inherent limitations in the file exchange and the shared database approaches of interoperability.

In many AEC project scenarios, sharing the entire project database or allowing all parties access to this database may not be a viable solution (e.g. for liability issues) especially where information needs to be shared across organizational boundaries. Also, developing an integrated view of project information and maintaining the consistency and integrity of data is a major challenge. Therefore, a centralized database approach would not work in many cases. Applications generally need to exchange a small subset of the project model that represents the overlap or the interface between their domains. Exchanging IFC files that store entire project models would be both inefficient and unpractical especially for large project models. Also, accessing online data repositories or data exchange between applications over the Internet would require exchanging project data at a finer-level of granularity where small chunks of the model data are communicated. Conducting online business transactions (e.g. procurement) or automating the data exchange process is not supported using these two forms of interoperability. Also, the data exchange process itself is still conducted manually through human intervention in an ad hoc and informal manner. Full or partial automation of routine project processes would require adopting standard protocols that define the context of these exchanges.

A message-based transactional form of interoperability is a more flexible, efficient, and generic data exchange mechanism that could virtually support all IFC-based information exchange scenarios in AEC projects, which could be used to complement and overcome the limitations of the two aforementioned forms. Interoperability protocols are information exchange protocols that formalize and standardize the exchange mechanisms between different parties and applications such that the effect of sharing a centralized and global project data model can be emulated. In effect, organizations and their applications exchange messages to synchronize their views of the project information and to maintain a consistent representation of various project aspects.

While the IFC model standardizes the information content of an information exchange transaction, it offers no guidance to the context of these transactions. It is still left up to the two parties exchanging information to come up with ad-hoc agreements about what data are being exchanged, for what business purpose, with what constraints and obligations on each participant, etc. Achieving interoperability through message communication between various applications and across organizational boundaries has been rarely studied or implemented in the industry. Given the fact that a large portion of the information exchanged in the course of a typical AEC/FM project can be modeled and more efficiently communicated in the form of messages, the need to develop a standard to enable different AEC/FM applications to exchange transactional messages in an intelligent, consistent, and automated manner becomes apparent. Standardization of the transactions will potentially provide better communication, increased quality, productivity, and reduced costs, and delays in the industry.

A Methodology for Developing IFC-Based Interoperability Protocols

The objective of this work is the formalization and possible standardization of message-based information exchange protocols to harmonize the transactional interfaces between heterogeneous and distributed AEC systems based on the IFC model. Two major requirements need to be satisfied in order to realize this objective: (1) Defining standard industry-wide data models to enable different applications to interoperate and exchange project information in a neutral format; and (2) Defining standard protocols that parties and systems could use to exchange information. The first requirement has been fulfilled by the availability of mature and comprehensive standard data models which can now be used to support exchanging wide range of project information in the form of neutral files or database systems. Developing such data models was the focus of much of the research for at least a decade. However, efforts to standardize information exchange protocols have been very limited. This work is motivated by the need to fulfil the second requirement.

Given the scope and long-term vision of this objective, an IAI project was recently launched to undertake the process of developing these protocols. The project involves several activities that will be conducted in an iterative and evolutionary manner to define these protocols and to validate them through series of pilot implementations of several use cases. Six main research activities have been defined (Figure 1). This section outlines our research methodology, and subsequent sections will discuss the main research activities and describe the requirements of each of these activities.

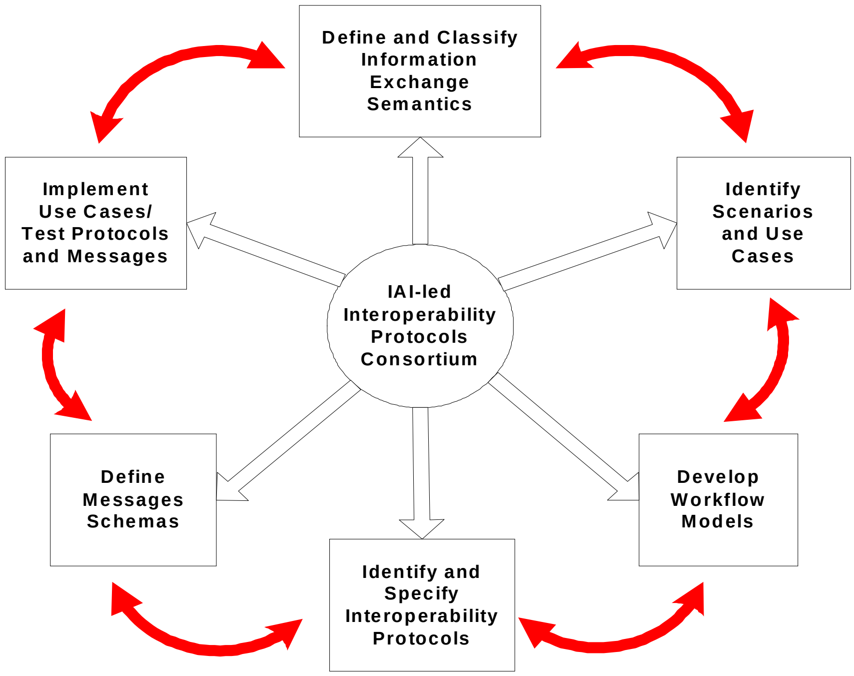

Figure 1: Methodology for Developing AEC/FM Interoperability Protocols

Fulfilling the first requirement for formalizing information exchange protocols would require the use of a common, consistent, and unified data model that could describe the types of information involved in AEC/FM transactions and serve as a shared dictionary to support intelligent exchange of project information. The data model should be comprehensive enough to support the information requirements of a wide range of project processes. The IFC model is a mature, comprehensive, and semantic-rich data model that is widely accepted and supported by the industry. In the proposed methodology, the IFC model is used as data dictionary that defines the vocabulary and semantics necessary to represent, share, and exchange information about AEC projects products and processes as the infrastructure to define the interoperability protocols. The IFC model defines an integrated schema in the form of a class hierarchy of AEC/FM objects, to support interoperability among various software tools.

Specification of interoperability protocols also requires the use of a neutral, semantic-rich, and efficient language to support communication among different systems. XML is emerging as the preferred language for Internet communication because of its richness, simplicity, and being supported by standard web protocols. Therefore, our work will be primarily focused on defining the protocols using XML messages based on the IFC data model. This way, we would complement other ongoing efforts, in particular IFC extension projects, ifcXML and aecXML, and avoid any redundancy in data modeling or representation and communication languages. Another related IAI project focuses on defining methods to use IFCs to define libraries and methods to reference these libraries from project-specific objects.

The proposed methodology for developing the standard interoperability protocols can be summarized as follows. To develop the interoperability protocols that support specific project scenarios, the processes involved in such scenarios need to be formalized and modeled to identify the information flow between these processes. The requirements for the information that needs to be exchanged among these processes are then identified and formally represented using the IFC data model. Also, the information exchange semantics need to be identified and classified. The information requirements and exchange semantics will be used to formally specify a set of protocols that are necessary to support the given scenario. A set of common and generic protocols that can support a wide range of scenarios to exchange project information are identified. Specification of the protocols requires identifying the workflow (i.e. sequence, dependencies, and information requirement of each activity) and message content (information, sender, receiver, etc.). For each protocol, one or more message may be required. Message formats will then be defined as XML schemas. The specifications will then be validated through implementing a set of prototypes and evaluate the efficiency of the process and the information exchange between various systems. The results of testing and evaluation of the prototypes will be used to refine and enhance the process model or the protocols specifications. Industry partners will also be involved in the specification and implementation aspects of the protocols. This process will be used to support a number of scenarios and use cases. As our understanding of the protocols and the characteristics of the scenarios increases, the set of protocols will be further optimized and eventually a limited set of generic protocols can be reached.

Developing Use Cases and Workflow Models for AEC/FM Project Processes

A substantial body of knowledge is currently available that addresses the analysis and modeling of the workflow of project processes in building construction. These models have identified important elements in AEC project processes such as project activities, roles, and information flow and requirements between different activities and roles. Workflow models are a good tool to provide an encompassing view of different roles, software tools, information requirement and flow, and project activities, and to identify the interface between activities and organizations and the required interoperability protocols for specific project processes.

Defining interoperability protocols would start by analyzing and modeling a number of specific use cases and project scenarios that we need to support. A number of common AEC use cases and scenarios have been identified, analysed, formalized, and modeled. (Pouria et al, 2002) presented the workflow models of two such scenarios: a document review process and a material delivery processes. The workflow models are represented using UML activity, swimlane, and sequences diagrams. The models demonstrate the interaction sequences of information flow between project roles, software applications, conditional logic, and start/end states. More workflow models are being developed to address change management, request for quote, procurement, and request and update of design and schedule IFC-based information.

Once the workflow models are developed, they will be reviewed and validated by a group of industry practitioners, and refined until they reflect actual industry practices. Within the scope of each workflow model, the protocols needed to support different interfaces will be defined and classified. Each interface between two processes in the model would be supported by one or more protocols. Protocols should be as generic as possible to support different scenarios.

Specification of IFC-Based Interoperability Protocols

Interoperability protocols are XML-based system-to-system messaging interface standard that will enable AEC organizations to exchange project information in a standardized and consistent manner. The protocols define the information exchange semantics and the XML messaging interface to support system-to-system transactions. The protocols describe "what" information systems need to exchange rather than "how" each system generates or uses this data, or how data get transferred. Interoperability protocols specify the communication transactions and interfaces between software applications running across organizational boundaries and describe the messages exchanges required to support a specific transaction. These protocols play the same role of the RosettaNet Partner Interface Processes (PIPs).

Interoperability protocols are syntax-independent neutral specification of information exchange semantics that could support a wide variety of syntactical representations. Since the exchanges will be using the web as its transport infrastructure, using XML would probably be the most preferred alternative. By only standardizing the messages semantics and XML schema, the protocols will be implementation-independent. Specifically, the interoperability protocols specification will mainly include:

1. *The definition of the supported business processes and workflow models*. The models will show the project processes, roles, and type and requirements of exchanged information. The workflow model will be represented using UML activity, swimlane, and sequence diagrams. Within the context of each workflow model, a number of interoperability protocols will be identified and described.
2. *XML schemas definitions describing messages structure and content*. Each protocol will be supported by one or more messages. Message fields could include information in the form of documents or IFC objects.

3. *Protocol Context Properties*. A number of control properties may be required to specify the context of each protocol. These properties address issues such as security options, authorization, authentication, non-repudiation, acknowledgement time limits, etc.

At the implementation level, messages encoding and communication issues as well as protocol context properties will be addressed. Although some of the protocols context issues could be standardized for specific AEC processes, we believe that these issues, although identified at the protocol specification level, should remain part of the implementation stage where specific values can be agreed-upon or negotiated by the collaborating partners. Given the nature of the AEC industry and the wide variety of organizational-specific and project-specific issues that determine the exchange contexts, leaving these contexts to be addressed at the implementation level seems more practical. In other more homogeneous industries, e.g. RosettaNet, these contexts are specified at the protocol levels.

Conclusions

The requirements and a methodology for developing, implementing, and possibly standardizing, a set of message-based protocols for exchanging AEC information have been presented. The definition of the workflow models, protocols, and messages will be developed, refined and extended in an iterative and evolutionary manner until they reach a level of maturity and stability that they could become an industry standard. The set of protocols and messages will be extended and modified in the future according to the industry requirements. Formalizing and standardizing AEC information exchange messaging protocols and defining an industry-wide consistent semantics to data exchange scenarios would potentially provide a number of benefits to the industry, such as:

- Exchanging project information in a consistent and efficient manner, which will enable the development of software tools to fully or partially automate routine project workflow processes;
- Standardizing the information exchange protocols will enable organizations to adopt consistent and more efficient AEC processes.
- Heterogeneous and distributed software tools running within or across organizational boundaries will be able to intelligently and efficiently exchange project information;
- Project teams and their software applications will be able to collaborate and exchange project information in a timely and efficient manner.
- Leveraging the industry use of the Internet, and IT in general. By supporting standard protocols, organizations and their software tools will be more accessible and visible. Industry-wide data and knowledge repositories can also be accessed and queried in a standardized format.
- Reducing project time and cost while increasing quality and productivity.

Acknowledgements

We gratefully acknowledge support for this work from the Natural Sciences and Engineering Research Council of Canada, Collaborative Research Opportunities Program.

References

1. aecXML, http://www.iai-na.org/domains/aecxml.html
2. Almeida, L, Grilo, A., Rabe, L., and Duin, H., "Implementing EDI and STEP in the construction industry," proceedings of Product and Process Modeling in the Building Industry, ECPPM'98, R.Amor (Editor), BRE, 1998.
3. cXML, www.cxml.org
4. Construction Industry Trading Electronically, http://www.cite.org.uk/
5. Electronic Business XML(ebXML) (2002) "http://www.ebxml.org/" (last accessed March 2002)
6. Halfawy, M.R., A Multi-Agent Collaborative Framework for Concurrent Design of Constructed Facilities, Ph.D. Dissertation, Department of Civil Engineering, The Ohio State University, (1998).
7. IAI, International Alliance for Interoperability, http://www.iai-international.org, (2002).

8. Khedro T., Facility Design and Construction Integration Through Cooperative Network Communications, http://www.stanford.edu/group/CIFE/FCDA/ICCCBE95.html (1995).
9. Pfeiffer H. K. C. The Diffusion of Electronic Data Interchange, *Physica-Verlag Heidelberg*,(1992).
10. Pouria, A., Halfawy, M., and Froese, T., Developing AEC/FM Transactions Standards, submitted to the Concurrent Engineering in Construction conference, Berkeley, CA, July 2002.
11. RosettaNet http://www.rosettanet.org, (2002)
12. Simple Object Access Protocol (SOAP), http://www.w3.org/TR/SOAP, (2002)
13. Wix, J. and Liebich, T., "Information Flow Scenario," Intelligent Service Tools for Concurrent Engineering (ISTforCE), http://www.istforce.com, (2001)
14. XML/EDI – the e-Business Framework, http://www.xmledi-group.org, (2002).

HYPERLINKHYPERLINK