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A loosely coupled system integration approach for decision support in facility management and maintenance

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ABSTRACT

With the objective of providing the best decision support to facility management and maintenance, this paper presents an agent-based, serviced-oriented approach for integrating data, information, and knowledge captured and accumulated during the entire facility lifecycle from its project planning, design, construction, material/component/equipment procurement, to operation and maintenance. All data/information/knowledge sources and hardware/software applications are loosely integrated through agent-based web services, either proactive or reactive, to provide decision support over all stages of the facility lifecycle, and particularly to optimize facility operations and maintenance. Case studies have been conducted with proof-of-concept prototype implementations to validate the proposed approach.

1. Introduction

A study by the US National Institute of Standards and Technology (NIST) [1] identified and estimated the efficiency losses of $15.8 billion in 2002 in the US capital facilities industry resulting from inadequate interoperability among computer-aided design, engineering, and software systems. FIATECH studies [2] went further and identified major causes of productivity problems and challenges in the increasingly complex construction industry environment including: poor access to accurate data/information/knowledge in a timely manner; lack of interoperability between software systems; lack of an integrated view of multiple domains for decision support; lack of integrated and scalable solutions; lifecycle problems not well understood and addressed; and, inability to assess uncertainties, risks, and the impact of failures.

In its vision on Lifecycle Data Management & Information Integration as defined in the Capital Projects Technology Roadmap [2], FIATECH envisioned that "the execution of future capital projects and operation of capital facilities will be radically enhanced by seamless access to all data, information, and knowledge needed to make optimal decisions in every phase and function of the capital project/facility lifecycle."

During the past few years we have been working towards developing integrated intelligent decision support tools for the management and maintenance of critical facilities. We envision that such decision support software tools will ultimately integrate project and process information from facility design and construction, historical and current real-time information from facility operation and maintenance, as well as real-time data and analysis results from facility condition monitoring and assessment. These tools will also need to integrate or cooperate with existing facility operation management systems and computerized maintenance management systems as well as other related systems including geographic information systems and enterprise resource planning systems.

Based on our previous experience in the related fields, we believe that an agent-based service-oriented integration approach is appropriate to achieve such a vision. This paper presents a conceptual framework of the proposed agent-based service-oriented integration approach for facility lifecycle information integration, with a particular objective of providing decision support to facility operation management and maintenance management. The rest of the paper is organized as follows: Section 2 reviews the related research literature; Section 3 describes the proposed conceptual framework and discusses key concepts proposed and developed in this work; Section 4 presents a case study and proof-of-concept implementation; and Section 5 provides a brief conclusion and some discussion of our future work.

2. Literature review

With the rapid advancement of information and communication technologies, particularly the Internet and Web-based technologies during the past two decades, various system integration and collaboration technologies have been developed and deployed to architecture, engineering, construction, and facility management (AEC/FM). After many years of R&D, the AEC/FM industry has now started to embrace and adopt software systems that support and promote the concepts of integration and interoperability [3]. However, due to the unique characteristics of the construction sector, the development and deployment of system integration technologies in AEC/FM are lagged behind other sectors. We have conducted a comprehensive literature review on this

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topic [4]. Here is only a brief summary of the research literature related to the integration and sharing of data, information, and knowledge throughout the facility lifecycle for decision support in facility management and maintenance. In fact, other important perspectives including economic, technical, technological, infrastructure, qualitative, and legislative should also be taken into consideration when providing decision support in facility management [5], but those aspects are beyond the scope of this paper.

The very basic idea for enabling interoperability between two or more applications is to make them first communicate, share or exchange information, and then inter-operate in order to achieve a common objective. We view system interoperability from two different perspectives: data interoperability and framework interoperability. While data interoperability is preferable to achieve efficient system integration and effective collaboration, it is not practical for the integration of legacy software applications that were initially developed by different vendors and were not expected to work together [4]. So incorporating legacy systems and achieving framework interoperability at a higher level is a challenge currently faced by the construction industry. In order to achieve framework interoperability, various technologies have been proposed, developed, and deployed.

Early simple integration uses a Web-based three-tier system architecture. As we discussed in Ref, [4], a simple Web-based system may be adequate for daily construction project management, but it is not sufficient to meet the requirements of facility lifecycle information integration.

A popular integration approach is based on the object-oriented programming paradigm that can be traced back to the 1960s and has been widely used in various application domains for about two decades. It uses a centralized or tightly-coupled integration approach and emphasizes programming efficiency by stressing the modularity of data structures and code sharing. It has been used for system integration, particularly after the development and deployment of three major Distributed Objects standards: CORBA by the Object Management Group (OMG), COM/DCOM by Microsoft, and Java RMI.

Faraj and Alshawi [6] presented an object-oriented implementation of a rapid prototyping environment called SPACE (Simultaneous Prototyping for an Integrated Construction Environment) which supports a subset of a construction project lifecycle. A number of commercial software packages were integrated including AutoCAD/AEC, World Tool Kit (for visualization in virtual reality), and Super Project Expert (for planning) as well as several other applications developed in-house. A centralized (modularized) project model is used to connect all these applications. Halfawy and Froese [7] proposed building integrated AEC systems using smart objects. In the proposed approach, smart objects are 3D parametric entities that are enriched with the capability to represent various aspects of project information required to support multidisciplinary views of the objects, and the capability of encapsulating "intelligence" by representing behavioral aspects, design constraints, and lifecycle data management features into the objects. Halfawy and Froese [3] further extended the model-based approach (using smart objects) into a component-based approach with the widely used three-tier system architecture. In fact, this component-based approach can be easily extended to a service-oriented approach and implemented using Web services technology and related standards.

Similar approaches using distributed object technologies (particularly CORBA) can also be found in Refs. [8,9]. However, Lu and Issa [8] emphasize a loosely coupled integration approach, compared to the standard-based approaches like IFC-based integration [3,7,10]. We believe that such loosely coupled integration is easier to achieve when using software agents and Web services technologies as presented in this paper.

The application of intelligent software agents to system integration has also been studied for about two decades. Parunak [11] has analyzed where agent technology can be best utilized in industrial applications: "agents are best suited for applications that are modular, decentralized, changeable, ill-structured, and complex". The reasons often given for adopting an agent approach are linked to their being proactive object systems and to the simplification of the architecture of the software systems. The real gain obtained from an agent-based approach, however, often comes from a better description of the real world by focusing on objects rather than functions. When used appropriately, this leads to the desired modularity, allowing flexible simulations, better response and improved software reusability [4]. In addition, agents can cope with a dynamically changing world by performing dynamic linking, allowing them to handle ill-structured or rapidly changing situations in a more economical way [12]. There have been a few applications of the agent technology for system integration in AEC/FM: Bilek and Hartmann [13] presented an agent-based approach to support complex structural design processes in AEC; Lee and Bernold [14] proposed an agent-mediated communication approach to overcome the problem of information overload during a construction project; Reffat [15] proposed an approach for architectural design to be carried out collaboratively and synchronously inside real-time 3D virtual environments within which architects design with intelligent agents based on the view of situated digital architectural design; Rueppel and Lange [16] applied intelligent agents and Petri-Nets to support cooperation and coordination in distributed planning processes in civil engineering; Kim [17] reported an agent-based negotiation approach for distributed coordination of project schedule changes; Aziz et al. [18] presented a mobile collaboration support infrastructure by integrating the Semantic Web (to provide a framework for shared definitions of terms, resources and relationships), Web Services (to provide dynamic discovery and integration) and intelligent software agents (to help mobile workers accomplish particular tasks); Alda et al. [19] proposed and developed an integrated multi-agent and peer-to-peer software architecture for supporting collaborative structural design processes.

The application of service-oriented architecture (SOA) to system integration has been one of the most active research topics during the past decade. The basic Web servers are passive (or reactive), i.e., they only reply to requests from users, rather than actively or proactively sending data/information to users or other servers; neither do they cooperate or coordinate. The Web service technology officially proposed by W3C in 2002 is meant to address these challenges. In fact, it is very similar to the concept of Active and Proactive Web Servers that we proposed in 2000 [20].

Even though Web services and the Semantic Web have been widely used in system integration and collaboration in other domains (particularly in e-business applications), very few reported results have been found in AEC/FM. Akinci et al. [21] developed a semantic web-based approach to enable interoperability between two existing CAD and GIS platforms. Schevers et al. [22] reported the application of Semantic Web technology, particularly the Resource Description Framework (RDF) and the Web Ontology Language (OWL) to the implementation of a digital facility model for the Sydney Opera House. El-Diraby et al. [23] presented a domain specific taxonomy for construction management. Kosovac [24] presented a Web services based framework for managing information from heterogeneous, distributed, and autonomous data sources in AEC/FM with a pilot implementation. Wang et al. [25] presented a middleware framework for integrating heterogeneous building automation systems on the Internet (focusing only on the integration of building automation systems rather than over the building project lifecycle). Boddy et al. [26] proposed a process-driven approach by integrating software agents and Web services technologies for computer integrated construction. It is the most relevant to the work presented in this paper, but our approach focuses more on the loose coupling integration solutions for enhanced flexibility, reliability, and scalability. Another closest work reported in literature is by Ercoskun and Dikbas [27] where similar concepts are proposed but the proposed integration platform was still at the conceptual stage and "under development", and their focus was on CRM (Customer Relationship Management) in AEC/FM.