Automation in Construction 57 (2015) 222–238

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Integrating distributed sources of information for construction cost estimating using Semantic Web and Semantic Web Service technologies

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ARTICLE INFO

Article history:
Received 6 October 2014
Received in revised form 7 April 2015
Accepted 8 April 2015
Available online 30 April 2015

Keywords:
Cost estimate
Construction project
BIM
Construction resource
Semantic Web
Knowledge-based system
Semantic Web Service
Ontology
RDF
OWL

ABSTRACT

A construction project requires collaboration of several organizations such as owner, designer, contractor, and material supplier organizations. These organizations need to exchange information to enhance their teamwork. Understanding the information received from other organizations requires specialized human resources. Construction cost estimating is one of the processes that requires information from several sources including a building information model (BIM) created by designers, estimating assembly and work item information maintained by contractors, and construction material cost data provided by material suppliers. Currently, it is not easy to integrate the information necessary for cost estimating over the Internet.

This paper discusses a new approach to construction cost estimating that uses Semantic Web technology. Semantic Web technology provides an infrastructure and a data modeling format that enables accessing, combining, and sharing information over the Internet in a machine processable format. The estimating approach presented in this paper relies on BIM, estimating knowledge, and construction material cost data expressed in a web ontology language. The approach presented in this paper makes the various sources of estimating data accessible as Simple Protocol and Resource Description Framework Query Language (SPARQL) endpoints or Semantic Web Services. We present an estimating application that integrates distributed information provided by project designers, contractors, and material suppliers for preparing cost estimates. The purpose of this paper is not to fully automate the estimating process but to streamline it by reducing human involvement in repetitive cost estimating activities.

1. Introduction

Various qualitative and quantitative methods for construction and manufacturing cost estimation in terms of their requirements, methodology, limitations, and strengths have been investigated by Aram et al. [1]. The scope of our paper is limited to quantitative cost estimates prepared by contractors based on a complete set of design documents. With the advent of building information modeling technologies, estimators can digitally extract building element properties from a building information model (BIM) and transfer the data to an estimating application. Current commercial estimating applications extract BIM data using proprietary add-in programs. An add-in is a custom-made program that is designed for retrieving data from another application. For example, WinEst [2] software has an add-in program for transferring BIM element properties from an Autodesk Revit model [3] to a WinEst estimate. Mapping BIM data to estimating software assemblies requires human involvement and is usually a time consuming process.

Another time consuming activity in cost estimating is the process of updating the estimating application's material resource cost databases. Current estimating applications keep built-in databases of resource unit costs. Since resource costs are affected by economic conditions and continuously change based on supply and demand, estimating applications' unit-cost databases must be updated before starting a new estimate. Currently, material supplier data are quoted in formats that are suitable for human consumption and are not processable by computer applications. Therefore, estimating application databases can only be updated manually.

The process of understanding information that is created in other sources is human-intensive and requires employment of specialized human resources. Presenting the required information for cost estimating in a computer processable format can greatly improve estimator's efficiency [4]. Semantic Web [5] technology provides an infrastructure and a data modeling format that enables sharing and combining information over the Internet in a machine processable format. Semantic Web uses formal ontologies [6] to describe the organization of data distributed over the Internet. Ontologies are explicit formal specifications of the concepts in a domain and relations among them [7]. Ontologies can be shared with computer applications to enable processing data that are generated in other sources. A knowledge base is an information repository created based on ontologies that provides means for

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http://dx.doi.org/10.1016/j.autcon.2015.04.003
0926-5805/

collecting, organizing, and sharing information. Semantic Web is intended to build distributed knowledge-based systems [8].

In this paper, we present a semantics-based estimating application that combines information from a building information model (BIM) knowledge base, an estimating assembly knowledge base, and material suppliers' Semantic Web Services to prepare a cost estimate. We investigate how such knowledge bases and Semantic Web Services can be developed, and how a semantics-based estimating application can access these distributed sources of data over the Internet for cost estimating. We investigate how a semantics-based estimating application can reduce human involvement in estimating activities for: 1) mapping BIM element data to estimating assemblies, and 2) updating estimating material resource cost databases.

2. Current construction cost estimating applications

To estimate the cost of a work item in a project, one needs to know the work item quantity and the unit costs for the resources necessary for its construction. Current estimating applications keep built-in databases of assemblies, work items, crew make-ups, crew productivities, and resource (material, equipment, and labor) unit costs. A cost estimating application provides the infrastructure to digitally map an element in a BIM to an estimating assembly which is a predefined group of work items, as shown in Fig. 1.

Current computer cost estimating applications require a number of time consuming, repetitive, and error-prone steps including:

1. An add-in program that facilitates digital transfer of BIM element properties to the estimating application. An add-in program requires human intervention for mapping BIM element properties to their corresponding estimating assembly properties which is a time consuming process.
2. Resource unit costs continuously change; therefore, an estimating application's resource database must be updated before a new estimate. This is a time consuming process that requires estimator involvement for obtaining the latest unit costs from various material suppliers and updating the estimating software's material resource databases.

The above inefficiencies occur because of the way estimating applications are developed and estimating data are stored. Almost all current computer cost estimating applications are modeled and developed using object-oriented technology and estimating data are stored in relational or object databases. As discussed by the W3C Semantic Web Best Practices and Deployment Working Group [9], the reusability of an object-oriented domain model is often limited because they are domain specific and only take into consideration abstractions needed to solve a problem within the confines of their own individual problem space. Some of the limitations of an object-oriented approach to domain modeling are [9]:

1. The domain schema is local and cannot be shared among applications or on the web. Therefore, two applications cannot share information without a custom-made add-in program or using a standard data format.
2. Application schemas cannot be dynamically modified. Any changes in an application schema would require revising the software written for the schema. In construction cost estimating, this would require a new add-in program for a new version of a BIM application.
3. Each domain develops a separate class hierarchy for the same set of objects; for example, the same building would be modeled using two different class hierarchies in the design and the estimating domains. This means the same element in the same building would belong to two different classes. However, in object-oriented systems, classes defined in different domains to represent the same object cannot share instance properties.

These limitations have made it difficult to share and combine information among various construction domain applications. In the following sections, Semantic Web technology is introduced and a semantics-based construction cost estimating approach is presented. The new cost estimating approach significantly reduces human involvement in routine, repetitive cost estimating tasks.

3. Semantic Web

The current web infrastructure is a distributed network of web pages that can refer to each other using Uniform Resource Locators (URLs) and is suitable for human consumption. Semantic Web is a network of connected data that are machine accessible and processable [10]. It can be seen as a graph in which each node is an instance that is pointing to other nodes. Therefore, a semantic definition of a construction project enables project participants to represent their information in a graph structure and easily combine and connect their information about the project [11]. Such an infrastructure makes distributed data connected and enables applications to search for and find data distributed on the web. Semantic Web enables creating data models, drawing meaningful conclusions from encoded knowledge, and sharing information on the web and between computer applications [12]. Semantic Web allows sharing model schemas and enables computer applications to process and draw conclusions on data that are generated in other sources [13].

Semantic Web technology uses ontologies [6] to describe a domain. Ontologies explicitly define the concepts, relationships among the concepts, and the relevant terminology in a domain of interest [7]. Ontologies can be imported and used for knowledge representation. This gives computer applications awareness of the organizations of the data distributed over the Internet. A domain ontology and a set of the

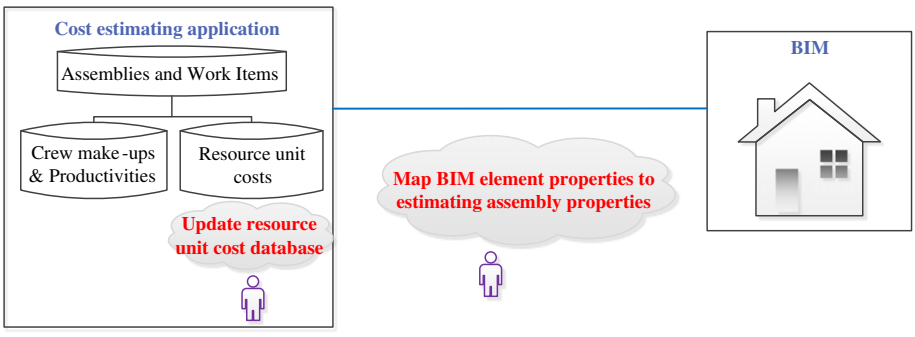

Fig. 1. Current estimating application.