Automation in Construction 45 (2014) 107–118

Contents lists available at ScienceDirect

Automation in Construction

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

Creating flexible mappings between Building Information Models and cost information

Michael Lawrence [a], Rachel Pottinger [b], Sheryl Staub-French [c,*], Madhav Prasad Nepal [d]

[a] Google Inc., 747 6t St S, Kirkland, WA 98033, United States
[b] Department of Computer Science, University of British Columbia, Vancouver, BC V6T 1Z4, Canada
[c] Department of Civil Engineering, University of British Columbia, Vancouver, BC V6T 1Z4, Canada
[d] School of Civil Engineering and Built Environment, Queensland University of Technology, 2 George St GPO Box 2434, Brisbane, QLD 4001, Australia

ARTICLE INFO

Article history:
Received 7 August 2013
Revised 24 April 2014
Accepted 10 May 2014
Available online 4 June 2014

Keywords:
Mapping
BIM
Query
Cost estimate
Design changes
IFC
Views
XML
Schema
Database

ABSTRACT

During the early design stages of construction projects, accurate and timely cost feedback is critical to design decision making. This is particularly challenging for cost estimators, as they must quickly and accurately estimate the cost of the building when the design is still incomplete and evolving. State-of-the-art software tools typically use a rule-based approach to generate detailed quantities from the design details present in a building model and relate them to the cost items in a cost estimating database. In this paper, we propose a generic approach for creating and maintaining a cost estimate using flexible mappings between a building model and a cost estimate. The approach uses queries on the building design that are used to populate views, and each view is then associated with one or more cost items. The benefit of this approach is that the flexibility of modern query languages allows the estimator to encode a broad variety of relationships between the design and estimate. It also avoids the use of a common standard to which both designers and estimators must conform, allowing the estimator added flexibility and functionality to their work.

1. Introduction

Accurate and timely cost feedback is critical for design decision-making on building construction projects. In the early phases of design, this is a significant challenge for estimators as they must create detailed and accurate cost estimates although the design is still evolving and changing and there is often incomplete information. Repeated changes in design parameters, component types and materials often occur to meet a project's budget, performance requirements, and to improve constructability. These design changes not only necessitate changes in material quantities, but they may also impact other aspects of the cost estimate that are more subtle and difficult to detect, such as changes to labor productivity rates, construction methods, and related cost items. Currently, determining how a design has changed and how it impacts construction costs is a laborious and largely manual task for cost estimators.

Building Information Modeling (BIM) is an increasingly popular enabling technology for digitally representing building information and supporting information exchange in the architecture, engineering, construction and facilities management (AEC/FM) industry. BIM standards are strongly product centric and oriented towards design practitioners. Extracting relevant information for construction practitioners, and in particular, in support of cost estimating remains a challenge. It is important to emphasize that one challenge is that BIM and cost estimating approaches use different *schemas* — representations of the data. For example, the BIM schema in Fig. 10 is very different to the cost estimate in Fig. 11. This is inherent in the problem — because the BIM and cost estimation communities have different sets of vocabularies, there is no one overriding schema that describes all, as we discuss in more detail when we describe related research (Section 3).

Existing approaches and software applications for BIM-based cost estimating attempt to automate the process of quantity takeoff (creating and managing sets of material quantities) and the selection of labor items and equipment needed to construct building components of a specific type. These approaches however suffer from the following limitations:

- Their dependence on detailed component information limits their usability during the early phases of design. For example, millwork specifications may not be given until much later in the design phase.

* Corresponding author. Tel.: +1 604 827 5118.
E-mail addresses: mlawrence@google.com (M. Lawrence), rap@cs.ubc.ca (R. Pottinger), sherylsf@civil.ubc.ca (S. Staub-French), madhav.nepal@qut.edu.au (M.P. Nepal).

http://dx.doi.org/10.1016/j.autcon.2014.05.006
0926-5805/

- Their rule-based approach is rigid and does not consider the cost-estimating impact of more abstract or subtle construction conditions. For example, the number of concrete columns offset from major grid lines may be relevant to the unit rate of column formwork.
- They are strongly coupled to the choice of design software, meaning the estimator's process must be tailored to suit the designer's. As discussed in [1], there is considerable variation in the procedures used to create a BIM by different design firms.
- They do not handle design changes beyond changes to material quantities well. Cost estimators are often interested in knowing the specific differences between successive design revisions and their ramification on cost estimates.
- The process of estimating involves more than just extracting counts and measurements. It involves assessing conditions, such as unusual wall conditions, unique assemblies, and difficult access conditions in the project that impact cost. Automatic identification of these conditions by any BIM tool remains a big challenge [2].

We address these limitations by proposing a generic approach for creating and maintaining a cost estimate by using mappings to relate cost information to a BIM. Our approach executes queries (i.e., formal instructions that tell the computer how to answer questions), both over the building design, and views (i.e., saved query results) over the design data. This approach of using views is an established mechanism for allowing independence between the models/standards used on both the design and estimate [3,4]. We propose a system whereby the cost estimator creates queries on the building design that are used to populate views, and each view is associated with one or more cost items. While creating a query of this sort may be difficult for an estimator, there are tools that can help with this process [5], and our future work includes having a graphical user interface where these queries are hidden below the surface. However, the benefit of this approach is huge: the flexibility of modern query languages allows the estimator to encode a broad variety of relationships between the design and estimate — beyond the typical case of material quantities. It also eschews the use of a common standard to which both designers and estimators must conform, allowing the estimator to add on functionality to their existing process.

The remainder of this paper is organized as follows. In Section 2, we introduce the study which motivated our research, and describe the application of modern BIM-based cost estimating software to this case. In Section 3, we review recent literature on cost estimating in BIM, and outline the tenets guiding our approach. Section 4 describes the details of our approach and the types of mappings it can handle. The aspect of system design and operation is discussed in Section 5. In Section 6, we describe a user study that we designed based on the case study introduced in Section 2 to demonstrate the benefits of our system and gather additional insights, and conclusions are then provided in Section 7.

2. The case study

Our approach is guided by a case study of a recently constructed building in British Columbia, Canada. This facility is a 93,000 SF, $31 M building which includes a lecture theater, office space, wet and dry laboratories, and animal care facilities. Fig. 1 shows a 3D rendering of the case study project. We obtained two detailed cost estimates (CP1 and CP2), prepared at 16 weeks apart in response to the changes in design, as well as the architectural and structural drawings corresponding to CP2. The cost estimates are tables of cost items organized according to the MasterFormat standard and each item has the following attributes: code, description, quantity, unit of measure, rate per unit, and total cost. We also obtained the files used to generate material takeoffs using *On-Screen Takeoff*, which is a program for calculating quantities based on digital drawing sheets (this is discussed in more detail below). The architectural and structural drawings are both electronically annotated using *On-Screen Takeoff*. We analyzed the differences between the two cost estimates, and interviewed the cost estimators familiar with the project working for the general contractor. We confirmed how the design had changed between CP1 and CP2, as well as details on the quantity takeoff and cost estimating process used for this project. We recreated a subset of the building design in a BIM using Autodesk *Revit*, incorporating all of the details (e.g. material layers) specified in the drawings into our model, which was then exported as Industry Foundation Classes (IFC) and converted into ifcXML. We used the case study BIM to evaluate state-of-the-art BIM-based applications and the ifcXML version of the case study to test our prototype application.

The cost estimator for the case study relied on *On-Screen Takeoff* to calculate material quantities from a digital set of building drawings. The estimator created a number of “conditions”, each corresponding to a type of component in the design. The estimator then annotated the drawings (lines, polygons or points) to represent quantities of interest (areas, lengths, etc.) on the drawings and associated each with a condition. Fig. 2 shows a snapshot of a portion of the structural plan for the basement level, where a number of conditions have been created for slab on grade concrete, footings of various types and walls.

Creating these conditions allows for a detailed takeoff to be performed, as the necessary quantities are calculated automatically from the visual conditions. Fig. 3 shows the quantities derived for a few of the footing items. In most cases, their perimeter, area, and volume are given.

For simplicity, we will focus on a few items related to concrete footings, which includes items for footing forms, rebar, and concrete. In order to specify quantities for these items, the cost estimator must add up a measure of all footings (although we only show a few, there are 20 such items). In the case of footing forms, the cost estimator must manually calculate the sum of all footing areas, and convert it to

Fig. 1. 3D rendering of the case study project.