WEB-BASED APPLICATION ON COST ESTIMATION OF CURTAIN WALL SYSTEM

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ABSTRACT: Using curtain wall design as an example, this paper studies the exchange of data involved in the cost estimation process among different parties and across different stages of the design process, and discusses web-based platform to support both the exchange and the storage of cost estimation data.

KEYWORDS: Cost estimation, curtain wall system, building information modeling (BIM), project life cycle management

RÉSUMÉ: En utilisant la conception de mur-rideau à titre d’exemple, ce document étudie l’échange de données impliquées dans le processus d’estimation de coûts entre les différentes parties et à travers les différentes étapes d’un processus de conception, et examine l’utilisation de plateforme internet pour échanger et stocker des données d’estimation de coûts.

MOTS-CLÉS: Estimation de coûts, système de mur-rideau, modélisation des informations de construction (BIM), gestion du cycle de vie d’un projet
1. BACKGROUND AND SCOPE

Building enclosure system plays a major role in the overall construction cost of building (Hart 2008). Costs, prices and other types of financial information are central to the activities carried out on a project level and many information transactions involve some types of cost information.

Currently, data models are developed to support product and object model exchange with different industries, led by ISO-STEP international standards effort. The EXPRESS data model language technology was developed by industry-led efforts through the ISO organization. Recent main building product data models are IFC (Industry Foundation Classes)—for building planning, design, construction and management and CIS/2 (CIMsteel Integration Standard Version 2)—for structural steel engineering and fabrication.

There are two trends in IT: model-based systems and web-based system. Document management is one of several cornerstone technologies within web-based collaboration, along with other areas such as e-commerce.

This article emphasizes the second approach: an aspect of document management involves techniques such as text processing or picture recognition to extract partial structured and semantic information from unstructured documents in cost estimation. This aspect can be tightly linked to IFC data by using IFCs to structure data that is itself more loosely text and images.

2. PRIMARY GOALS

The main purpose of cost-estimation is to accurately capture the cost data required in the building design and avoid the risk of budget overrun at the later construction stage.

In this paper, the characteristics of cost estimation are being explored in an exterior enclosure system with level of detail that goes from stages of schematic design throughout design development, construction document, and construction administration. A system is proposed to support continuous cost estimating for the curtain wall system, at varying levels from the most limited sketch to a fully detailed design ready for fabrication.

It is anticipated to establish a data model to illustrate the information exchange of cost data between design team and cost estimator and develop a basic representation scheme for project-based data and product-oriented information. The link between model-based and document-based information is illustrative of the ways that these two important IT trends can be brought together. This paper will establish a set of rules or constraints between model-based information and document-based information to archive the goal.

Several levels of issues will be addressed in this paper: 1) the phase-based exchange of cost data between design team and cost estimator, and 2) the seman-
tic issues of workflow and functional specification of object, parts, geometry, attributes, relation and metadata. This paper also explores the representation scheme for project-based and building-oriented data from aspects of building, façade and panels through the building levels grid and structural system, the facade-level definition of control grid and lines for management of the façade, the edge condition definition for interfaces to other skin systems, and the panel level defining relation to facade grid and the pieces within a panel.

In a practical view, it is crucial to integrate cost data analysis editing, tracking and updating with data exchange in the curtain wall models. A user-editable data repository is anticipated to serve as a library for wall object components, with shape methods, attributes, relations and associated phase-based cost items in a project lifecycle management. In a web-based platform, the data retrieving, processing and document management can be collaborated in an efficient way.

3. CURTAIN WALL DEFINITION, TYPES AND ATTRIBUTES

3.1. Definition

Curtain wall is a term used to describe a building façade which does not carry any dead load from the building other than its own dead load. These loads are transferred to the main building structure through connections at floors or columns of the building. A curtain wall is designed to resist air and water infiltration, wind forces acting on the building, seismic forces (usually only those imposed by the inertia of the curtain wall), and its own dead load forces plus energy transmission.

3.2. Types of curtain wall

3.2.1. Stick System

The vast majority of curtain walls are installed in long pieces (referred to as sticks) between floors vertically and between vertical members horizontally. Framing members may be fabricated in a shop environment, but all installation and glazing are typically performed at the jobsite.

3.2.2. Unitized System

Unitized curtain walls entail factory fabrication and assembly of panels and may include factory glazing. These completed units are hung on the building structure to form the building enclosure. Unitized curtain wall has the advantages of: speed, lower field installation costs, and quality control within an interior climate controlled environment. The economic benefits are typically realized on large projects or in areas of high field labor rates.
3.3. Components of curtain wall

The components of curtain wall are listed as below:

- Frame (Steel or Aluminum)
- Infill (glass or panels)
- Anchorage (Anchors, Inserts, Support brackets, Stiffeners, etc.)
- Accessory (Sealants, Caulking, Joint Filler, Gaskets, Fasteners, Flashing, etc.)
- Insulation
- Finish

4. DIAGNOSIS AND SYNTHESIS

This section aims to investigate the functional requirements of lifecycle cost estimation method in a curtain wall system. It introduces the notion of semantic type and workflow, examines the characteristics of curtain wall system from IFC perspectives, and addresses the model view definition with construct/concept for implementation.

4.1. Semantic issues of workflow exchange

The critical issue behind data exchange lies in the better understanding of objects in which the functional specification of objects plays a major role. Since specifying a workflow data exchange requires defining all aspects for each exchange, it is expected that each object of interest is appropriately defined according to object class, shape method, part structure, relations, attributes, parametric rules and metadata. For accurate translation in building models, it is critical to establish a list of functional definitions for use in defining the information contents of Use Case and workflow data exchanges (Eastman 2008: Chapt. 3).

This approach can be characterized as the followings:

- Describe the activity, information exchange, and roles involved in a Use-Case study.
- Define different semantic issues associated with object identification, types of geometry options available, types of attributes and relations involved, and how this object may be related to others.

A Use Case is made up of possibly multiple information exchanges required to support data flows between two roles or disciplines, within a particular stage of design for a particular purpose. Functional classification is defined at two levels. The first level is to model exchange and second level is model specific, defining a data dictionary for a specific domain.

In order to specify a workflow data exchange, a typical BIM object can be defined according to: 1) object class such as wall, slab, curtain wall, HVAC part,
2) shape method such as B-rep, CSG solid, extrusion or other sweep, 3) attributes and properties, 4) relations: nesting, assemblies, connections and 5) part structures such as number of pieces and organization.

4.1.1. Shape Method

In IFC family, the curtain wall uses ‘BoundingBox’, ‘SurfaceModel’, ‘Brep’ and ‘MappedRepresentation’ representations of IfcCurtainWall supported in IFC. The conventions to use these representations are given at the level of the supertype, IfcBuildingElement.

4.1.2. Attributes and Properties

Curtain wall system is expected to address the following attributes and properties:

- Frame: steel or aluminum
- Infill (glass and panels): type, strength, thermal property, color, etc
- Accessory (sealants, caulking, joint filler, gaskets, fasteners, flashing, etc): type, strength, paint, color, etc.
- Insulation: type
- Finish: painting, galvanizing, etc.
- Performance Properties: structural, thermal, acoustic, fire rating, etc.
- Design Loads: live loads, snow loads, seismic loads, wind loads, thermal loads, load location and timing acoustic, fire rating, etc.

4.2. Model view definition for validation

The original purpose of MVD (model view definition) is to provide a specification for the IFC based technical solution for data exchange between software applications. This includes the scope and details of IFC implementations and enabling certification based on this specification. The goal is to create IFC based, reliable and useful data exchange capabilities for industry practitioners for either creating or consuming BIM data. A logically defined IFC subset is for implementation of a well-identified information item in model views. It validates once for all its uses and can be re-used in other use cases (NIBS 2007).

4.3. Definition of part, façade & building

Constructs, defined as composition of Concepts, joining the relations or “ports” and mating IFC type specification, regard functional requirements at different level of details. It is assumed that each Construct corresponds to an object type in the exchange map of Use Case.

In Figure 1, 2 and 3, the definitions of curtain wall system are illustrated using the notion of Construct-Concept, access condition, and levels of details.
needed in the design phases. The central objects, showing high-level definition of curtain wall system such as *curtain wall pieces*, *curtain wall piece type*, and *building level grid & structure system* are *Constructs*. The linked objects are *Concepts* which are object defined in the lower level.

These *Construct-Concept* trees are built on the entities of IFCcurtainwall and used to illustrate authoring parameters setting up from varied scale and to show taxonomic view of curtain wall system. It also describes functional specifications of assembly-part relation from installation and fabrication perspectives. Creating *Construct-Concept* diagrams helps describing part-assembly related to IFC attributes and product perspective and establishing a data model to know attributes, relations, and performance of selected system.

**FIGURE 1. PIECE DEFINITION OF CURTAIN WALL.**

**FIGURE 2. FAÇADE (TEMPLATE) DEFINITION OF CURTAIN WALL.**
4.4. Intelligent embedded parametric modeling design tool

Storing the required data in the appropriate format to archive and recreate the native project files is required by the various BIM authoring tools. The neutral format that the repositories carry data in is inadequate to recreate the native data formats used by applications, except in a few limited cases. The built-in behavior in the parametric modeling design tools is expected to enable any neutral format exchange information, such as IFC model data, to be augmented by or associated with the native project files produced by BIM authoring tools (Eastman 2008).

4.5. Project lifecycle management

Project Lifecycle Management is a business model which typically involves system integration of a set of tools, including product model management; inventory management; material and resource tracking; and scheduling. It is based on the needs for collaborative workflows, with incremental updates, review and insert, online review and discussion, and support for tight design-assess cycles, matching design state with assessment results. Its current implementation is primary on larger business and is expected to be tailored to have different kinds of use in AEC industry.

4.6. Method of cost estimation

During the early design phase, the only quantities available for estimating are those associated with area and volume, such as types of space, perimeter lengths, etc. In the schematic design of curtain wall system, the façade area is the major parameter adopted by CSI Master Format, which begins with the rate, the quantity, and the ratio; and, therefore, it associates with design allowance and contingency for a whole price package.
As design matures, it is possible to extract more design information (i.e. spatial and material quantities) in building models. These quantities are more than adequate for producing approximate cost estimates. For more accurate cost estimate prepared by contractors, problems may arise when the definitions of components (typically assemblies of parts) are not properly defined and are not capable of extracting the quantities needed for cost estimating. In building lifecycle, cost estimating is not merely the measurement for quantity takeoff. The process of estimating involves assessing conditions in the different phases of project. It is expected for an accurate cost-estimation that the automatic identification of building components, access conditions, and definition of all levels of parts, assembly and building become feasible.

This comes with a question: is the detailed information of building component available in the early stage of design?

In a traditional practice, design team tends to have more room for design intent exploration which leads to certain degree of abstraction in geometrical illustration. That is the reason why conventional estimating cost in early design is based on area, length, volume, weight etc.

Conventionally, a complete cost estimate is not available until design team has more detailed design information. It heavily relies on the accurate counts of building components/assembly which are typically generated in the later stages such as design development and construction document.

In Figure 4, it is anticipated that conceptual cost estimate is part of detailed cost estimate package. In other words, cost data in early stage of design could not be merely based on methods of area, length or volume. Instead, it could incorporate with more detailed information of cost objects such as parts and assembly.

**FIGURE 4. CONTINUOUS COST-ESTIMATION.**

4.7. Web-based collaboration

Historically, collaborative tools (such as e-mail, document management, and calendaring) have been the primary supports for knowledge management. The next generation of collaborative work will be defined by the shift from infor-
information handling to interaction management or socialization. Effective social networks among stakeholders of AEC industry might seem more critical for a successful collaboration. The emergence of social applications in the industry can enable the next wave of knowledge worker productivity.

Capturing cost data information about interactions and activities can improve productivity and provide accuracy into how to respond to iterative design process. Managing interactions via an internet-powered, user-focused, and community centric social fabric is at the heart of this web-based management. The advantages can be featured as following:

The short-term impact is a boost to individual and team productivity as user-provisioned tools; collaborative workspaces; and flexible, connected stakeholder networks (e.g. design team, owner, cost estimator and contractors) replace desktop applications, inefficient silos, and rigid hierarchical structures. A longer-term benefit of this application is a transformation in how cost-estimating adjusts to continuous design changes, resulting new approaches to project-based management development, cost tracking, and other operations.

5. PROPOSED SYSTEM

In general, the proposed system could have the following features:

- Cost data tracking and monitoring
- Curtain wall components generating and operating
- Knowledge-embedded mechanism
- Project Lifecycle Management

Specifically, the system should: 1) deal with frequent or real-time coordination between multiple application users, 2) support exchanges between multiple concurrent applications that read and write project data, 3) check product data model repositories, for logical correctness, for cost data checking and tracking with automatic reporting, and 4) embed levels of intelligent in the system.

5.1. Requirements for web-based model

To link to a web-based Project Lifecycle Management system, the basic features are listed as follows:

- Inquiry method (smart search)
- Quantity take-off
- Quantity attributes
- Surface area calculation, piece count method
- Rate library
- Installation allowances
- Fabrication allowances
- Design allowance
5.2. Requirements for product-based model

The basic features are listed as follows:

- 3D geometry component generator
- 3D geometry operator (mode, phase)
- façade definition
- parts (piece) definition
- building-level definition
- design allowance

In Figure 5, 3D components generator, similar to parametric modeler, serves to create 3D curtain wall components (assembly, parts, accessory, etc.). On the other hand, 3D geometry operator works for sorting, editing and evaluating appropriate phased-based components for quantity takeoffs. Criteria for selecting phase-based cost data is related to level of details in design tasks. For example, cost estimator needs only area, volume of curtain wall in schematic design while piece count probably plays a critical role in the stages of design developments and construction documents. In addition, a user-editable data repository is anticipated to serve as a library for wall object components, with shape methods, attributes, relations and associated phase-based cost items in a project lifecycle management.

**FIGURE 5. PROJECT-BASED AND PRODUCT-BASED MANAGEMENT OF CURTAIN WALL SYSTEM.**
5.3. Application for web-based system

The proposed portal is anticipated to have a user-centered interface, and serve as a custom-editable platform which users can define the required functions over time. It includes: 1) user-centered profile (firm, personnel), 2) easy-to-use interface for stakeholders, 3) wiki access, 4) blog and RSS function and 5) features of smart search.

5.4. Application for product-based system

It may incorporate the following systems: 1) IFC-based model, 2) parametric modeler, 3) knowledge-embedded system (smart system), and 4) Tracking/monitoring mechanism with write-back functions and user-editable attributes.

The joint applications between web-based and model-based applications are shown in Figure 6.

**FIGURE 6. WEB-BASED AND PRODUCT-BASED APPLICATION OF CURTAIN WALL.**

Furthermore, a mechanism to bring more detailed design information into the early stage of design is anticipated to test how real-time cost data coordination is accomplished. In Figure 7, a workflow is addressed which emphasizes the roles of 3D parametric model, built-in construction template and design options generation.

3D parametric model is central in this sub-system. It functions as an engine for generating necessary geometric data for cost estimation. This parametric model is supported by the following modules:

- a built-in construction templates with applicable construction details;
- a set of rule/logics which regulates the design data;
- a library with objects of parts/assembly.

Traditional cost estimation uses “recipes” to expand a unit of material into logistic, preparation, labor and material costs, an area in a building type and
can be expanded to the typical material usages to produce “expected” material quantities. This workflow, alternatively, enables the design team to generate more detailed data model in the early stage of design and if suitable construction templates are embedded in the system, generating design options becomes possible. This also helps to facilitate design data exchange, building components generation and operation among architecture, structure and analytic models.

In the early design stage, layout of façade in a 3D model of curtain wall system probably shows merely grid and subdivisions of metal frames and infill panels. But with the introduction of built-in construction templates, this subsystem enables design team to have “certain” details of building components derived from geometric profiles they choose. It shows not only an extrusion of line entity but also incorporates the required geometrical property and cost attributes of construction details.

Templates such as pre-defined components of curtain wall panels with a variety of glazing choices and types of metal frames are some of these examples. Later, design options are viewed as a set of pre-defined parametric assemblies and could be fully automatically generated. The curtain wall templates may be those of actual products, or custom systems with detailed cost estimates.

By utilizing features of “dash-board” or “push-button”, this user-defined port/mode enables design team and cost estimator switch back and forth between conceptual and detailed design phases for better cost assessment.

**FIGURE 7. METHOD OF COST-ESTIMATING AMONG STAGES.**
The built-in construction template (Figure 8) can be seen as a “container” where acquisitions of geometric information, criteria for material selection, and rules/logic for parametric objects are available so that design options associated with pre-defined assembly and components could be carried out without regard to time and place.

Communication is executed as a continuous process between stages to gain such competitive advantages as time efficiency through web-based collaboration. On the other hand, it serves to support creating building assembly, parts and accessory and works for sorting, editing and evaluating appropriate phased-based components for quantity takeoffs and setting criteria for selecting phase-based cost data relevant to level of details in design tasks.

**FIGURE 8. BUILT-IN CONSTRUCTION TEMPLATE.**

**6. SUMMARY OF WORK AND FUTURE STUDY**

This paper aims to propose the following aspects of continuous cost estimating in a curtain wall system:

- Understanding the semantic issues of curtain wall system which includes the material and spatial features, and the workflow among relevant stakeholders (design team, owner, fabricator, contractor, etc.)
- Implementing intelligent-embedded mechanism which allows smart search for geometry components and attributes and further evaluation on a quantity and quality basis.
- Facilitating rule-based assessment from parametric efforts for cost data tracking and evaluation.
The most fundamental issue behind continuous cost estimating is whether there is an inherent paradox in pairing preliminary conceptual design with a detailed cost estimate and ideally, a set of 3D BIM models should represent completeness of geometric objects and accuracy of cost estimate in different phases.

Given the simplicity of the model and how quickly it can be put together to produce estimates, it is difficult to know how accurate cost prediction in preliminary stage estimating methods produce compared with later design stages or even actual cost in construction.

A curtain wall system involves much technical issues in their design and fabrication, which leads to a more collaborative design and development process. Cost estimation also involves various components. It is not just a unit price. It needs to address issues of custom engineering of the product (the whole curtain wall) as required for this project, especially for material costs such as special metals and glass, fabrication costs, unit assembly or stick assembly and costs of transport, field preparation, erection, finishing at the most detailed level.

Future studies could emphasize the issues of how the design teams communicate their intent, and how this dialogue supported, leading to a final design? Furthermore, the development of continuous cost estimation of the system throughout design and then contracting requires more detailed assessment such as the role of detailed cost data in early design tasks as opposed to a “normative” or conventional design practice.

REFERENCES


NIBS, 2007, United States National Building Information Modeling Standard Version 1 – Part