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A Proposed Cost-Based Approach to Building Design

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Abstract
Cost estimates of a building project need to be maintained and monitored throughout the project life cycle. While current computer applications in estimating are helpful in assisting estimators with the creation of estimates by taking off quantities automatically, they are insufficient in supporting the collaboration between estimators and other project participants (i.e. architects, engineers, and project managers) in regard to maintaining the cost estimates as the design evolves and changes throughout the course of the project. Furthermore, existing software tools are unable to explicitly rationalize how a building component or system selected by a designer affects the overall project cost. This makes it difficult for the estimator to determine when and how to adjust the cost information in the case of design changes so that the cost estimate and project scope are in balance. This paper outlines a framework for a collaborative building design environment where all project participants, during the design process, are able to keep track of the affects of their designs on the overall cost of the project. Such a computerized tool will be helpful in not only assisting estimators in creating automatically cost estimates as well as making decision on cost adjustments to ensure the budget limit, but also allowing building designers to consider cost-efficient alternative designs during the design process.

Keywords
Cost estimate, computer applications, building design, and collaborative design.

1. Introduction

In a conventional building design process, various discipline-related design criteria (e.g. energy savings, budget limit, constructability, and code compliance) of a building are not evaluated until all design works for the building are completed. In the case that one of these criteria is not satisfied, for example the budget limit is exceeded, all project participants including designers, estimators, and the project managers are required to discuss and determine what building elements or systems most affect the overall cost of the project and should be changed or modified so that the project cost is cut down to the expected budget limit. Such a design process is found to be time-consuming and costly since the manual evaluation of building designs may be repeated through meetings over and over again until all the performance criteria or requirements of the building designs are satisfied. Additionally, the manual evaluation often overwhelms meeting participants who come from many different disciplines and often also different

organizations with many diverse sources of information to be discussed. At present, with computer supports the performance evaluations can be easily handled. For example, an estimating software linked to a CAD system can automatically generate the quantity take-offs needed for cost evaluation or estimates. Those current computer software, however, are unable to rationalize the selection of building elements or systems by a designer in terms of building performances. This research effort is to develop a framework underlying a computer-based building design system that is able to capture designers' rationale for how the selected components affect the overall building performance. For this particular research project, the building performance to be evaluated is concentrated on the overall cost of the building. The development of the proposed building design system is mainly focused on the implementation of the engine, named cost analyzer, which is responsible for creating cost estimates and performing cost analysis enabling designers to consider cost-effective alternative designs and also keep track on the effect of the building elements they select on the overall cost of the project.

1.1 Cost estimate

Cost estimates of a building project usually evolve along with design changes in different phases of the building design and construction process. As a result, it is critical that cost estimates need to be maintained and monitored throughout the project life cycle. Traditionally, cost estimates of building projects at a particular design phase are not created until all design works have been completed. Such a traditional design process may result in more design changes and reworks and the overall cost may finally exceed the budget. Although current estimating computer applications assist estimators in expediting the estimating process by automatically generating take-off quantities, they are unable to help estimators to interact with other project participants during the design phase so that any changes in design affecting the overall cost will be identified in real-time. Hence, the proposed building design approach is that the evaluation of design objectives should be carried out during the design process to provide feedback to project participants (i.e. estimators) immediately.

Most of large projects designed by an A/E firm are usually completed with many changes in the original design causing budgetary problems and it would take multiple project meetings to resolve such problems. Through these meetings, project participants could not evaluate and predict the performance of alternatives in terms of design objectives with any reliability because:

- Access to project information and the determination of the impact of the proposed changes to the design are carried out manually
- Graphical representations of the project are two-dimensional and they do not visually represent critical relationships between project information such as building performance, space, time, costs, etc. With this shortcoming, it is difficult to establish communication between project participants and to identify the element that has caused a design objective (project budget) to be violated.

1.2 Related research

Today, powerful CAD systems such as solid modelers or geometric modelers are able to describe 3D models. Several researchers (Eastman et al. 2002; Fischer et al, 2001; Haymaker et al., 2001; and Griffis & Sturts 2000) have taken the advantages of the 3D solid modeling techniques to develop computer-based systems with emphasis on the integration of various design and construction applications. In addition, the integrated use of multidisciplinary design applications in the building design systems leads to a need for a standard data protocol to support interoperability among different AEC (Architecture, Engineering, and Construction) applications. As a result, the current major effort in developing a building data model is based on the Industry Foundation Class building model (IFC 2001), which has been developed by the International Alliance for Interoperability (IAI). The IAI mainly consists of a wide range of construction industry organizations who have come together to fund the development of the IFCs in response to the need for a standard data structure to support data exchange among different AEC professionals.

1.3 Current research

The current research outlines the development of another component of the proposed building design framework, called Cost Analyzer. The Cost Analyzer is responsible for evaluating the overall cost of the project and for providing real-time feedback. The feedback concerning budget limits allows designers/estimators to identify the most cost-effective design alternatives.

The scope of the current research on cost estimate and analysis focuses on preliminary design because decisions made during this early design stage have a significant influence on the subsequent project phases as well as the overall project cost.

2. Selection of a CAD system

Recently, the emergence of solid modelers has offered solutions for the representation of 3D geometric information of design objects and has provided support for the addition of semantic attributes describing the design objects. Unlike traditional CAD systems, which are merely tools to graphically represent a design by means of primitives such as points, lines, and arcs, solid modeling provides various representation schemes using primitives such as vertices, edges, faces, cells, and loops. Such primitives are suitable for a complete and unambiguous description of design objects. Furthermore, using solid modeling, the objects observed in buildings can be quickly created as blocks, thus making it simple to perform calculations of volume and mass properties of the building objects. Such building information are necessary for different design activities (especially the task of cost estimate) throughout the design and construction process. There are many 3D geometric representation techniques including Boundary representation (Brep) and Constructive Solid Geometry, and Feature-Based Representation. This research makes use of 3D boundary representation or Brep of solid modeling for representing building objects. The representation provides both geometric and topological data necessary for deduction of spatial relationships between the building objects. In addition, the availability of Brep representation in a CAD software, such as AutoCAD, is useful for the development of the proposed building design system.

3. Programming Environment

The main objective of this research is to develop the component of cost analyzer in the proposed system to perform cost analysis of a building project. This can be done by means of a new command "CostAnalyzer" to be developed and incorporated into the AutoCAD system. The command "CostAnalyzer" is implemented in an application development environment named ObjectARX. This development tool is an AutoCAD® Runtime Extension programming environment that includes a number of C++ dynamic link libraries (DLLs) that enable developments of AutoCAD applications (ObjectARX, 2002). The main reason for selection of ObjectARX as a programming environment for the implementation of this work is that the set of DLLs in ObjectARX can operate directly with core AutoCAD data structures and code, thus providing suitable mechanisms for accessing AutoCAD database to extract data of design objects that are necessary for generating cost estimate and analysis: the main subject of this research. In effect, the ObjectARX DLLs share AutoCAD's address space and make direct function calls to AutoCAD, thus avoiding the costly overhead of the Inter-Process Communication (IPC) that is usually required by other alternative AutoCAD Development System (ADS) applications and AutoLISP.

4. The Proposed Building Design Framework

Figure 1 shows the overall framework underlying the proposed building design system. As the proposed computerized system is developed in a solid modeling (Brep) environment, each building component is represented by a 3D object. Such 3D representations enable complete description of building objects by means of various attached attributes such as time, cost, design criteria, etc. The main research challenge is to develop links between the geometric information contained in 3D CAD drawings with non-geometric information (e.g. unit costs) representing building objects.
The proposed system is designed to assist estimators in creating cost estimates automatically and monitoring the fluctuation of the overall cost throughout the building design process, mainly the preliminary stage. The system uses a single, expandable representation of the building and its context in terms of building assemblies such as floors, walls, windows, and roofs.

Figure 1. The Proposed Building Design Framework

This representation is internally mapped onto the computer geometric representations available in the 3D CAD tool, enabling automatic generation of material take-off quantities and cost estimates for a particular building assembly. The proposed system is developed on top of AutoCAD system and comprises of two major components: the AutoCAD editor and the design evaluator, i.e. cost analyzer. The AutoCAD editor provides building designers with 3D solid design tools to draw building components. The AutoCAD interface provides high-level and precise mechanisms for manipulating various types of geometric data structures and high-level geometric modeling objects such as prism, cylinder, polygon, line, etc. for creating basic design objects such as columns, beams, slabs, walls (Nguyen & Oloufa, 2001). These basic objects can be "assembled" to create more complex building objects such as rooms, floors, or construction zones. In the proposed building design system, generic alternative building components and systems can be created and grouped into different categories such as architectural systems, structural systems, mechanical systems, and electrical systems, which contained in separate “libraries”. These libraries of building systems allow designers to select the ones that support their own design intent. Once the designers have completed their designs for the building, the cost analyzer automatically extract information about cost estimate (e.g. take-off quantity of materials and unit costs) necessary for a cost analysis. This can be done by executing a new command, namely CostAnalyzer, which has been developed using an AutoCAD application development tool (e.g. ObjectARX) and added to the AutoCAD system. The final output including the generated cost estimate and analysis will be displayed in AutoCAD screen providing designers with a quick feedback on cost efficiency among different designed building systems

4. Conclusion

Design objectives concerning various performance aspects (e.g. energy efficiency, budget limit, constructability, code compliance, etc.) of a building project must be evaluated during the design phase to avoid or eliminate on-site changes that are usually costly due to rework. Building design systems should provide the project participants with the necessary feedback and information for implementing design objectives. Such computer-based systems must be developed in a suitable advanced CAD environment. Presently, many solid modeling techniques has offered feasible solutions for the representation of 3D geometric information of design objects as well as allowing the addition of semantic attributes. The proposed building design system makes use of 3D Brep techniques to represent building objects including both geometric and non-geometric data (e.g. unit costs and design criteria), enabling the automatic generation of cost estimate and analysis. The proposed approach is aimed at demonstrating the feasibility of using solid modeling techniques in representing building objects to support various design activities.

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