BIM-Based Engineering Measurement and Data Exchange Applied Research Postprint

Authors: Chen Jing, Yu Fangqiang, Yang Jie, Kuang Siyu

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Abstract

This study utilizes BIM technology to implement cost management in engineering cost estimation, establishing a technical solution for quantity surveying based on BIM technology within our company' s commercial division. Through comparative research on existing construction engineering cost budgeting software and the connection and deduction relationships of BIM components, the accuracy of BIM-based engineering measurement is validated; based on the valuation rules of bill of quantities, BIM modeling standards for quantity surveying and engineering quantity data exchange standards for BIM components are systematically summarized.

Full Text

Preamble

Research on Application of Engineering Measurement and Data Exchange Based on BIM

Chen Jing, Yu Fangqiang, Yang Jie, Kuang Siyu
(Shanghai Construction No.4(Group)Co.,LTD., Shanghai 201103, China)

Abstract: This study utilizes BIM technology to achieve cost management in engineering cost estimation and establishes a technical solution for our company to implement quantity calculation based on BIM technology in the business line. By comparatively studying current construction engineering cost budgeting software and the connection and deduction relationships of BIM components, the accuracy of BIM engineering measurement is verified. Based on the engineering quantity list pricing rules, BIM modeling standards for engineering quantity calculation and data exchange standards for BIM components are summarized.

Keywords: BIM; Deduction relationship; Engineering physical quantity; Quantity calculation; Data sharing

1 Introduction

BIM (Building Information Modeling) is a digital representation model of buildings that contains rich data and features informatization and parameterization. With the promotion and application of BIM, the functionality of building information models is no longer limited to three-dimensional visualization; models containing accurate component information offer significant advantages for quantity calculation and statistics.

BIM-based automated quantity calculation methods are more accurate and efficient than traditional manual calculations [1]. Most components in actual engineering projects are irregular in volume, making the calculation process extremely complex. Cost engineers are prone to calculation errors due to human factors, whereas BIM-based automated quantity calculation yields more intuitive and accurate results. Moreover, rapid calculation results enable timely feedback on design scheme costs, facilitating cost control throughout the early stages of the project.

1.1 Foreign Research Status

In foreign countries, BIM technology has developed relatively maturely, and its application in engineering cost estimation better aligns with market demands. Fara j et al. developed a Web-based project data engineering environment that enables integrated sharing of budget, project schedule, and other information in engineering projects [2].

Sheryl et al. applied the IFC standard to the development of a cost budgeting prototype system, utilizing component information and attributes from the model to automatically match quotas for cost budgeting, thereby achieving intelligent integration of quantity and price.

Furthermore, foreign quantity calculation software such as Vico and RIB iTWO are basically 5D BIM-based software that can manage costs and schedule planning during the construction phase. By associating BIM models with construction duration and cost expenses, data linkage across various disciplines during the construction process is achieved.

1.2 Domestic Research Status

In China, there are primarily three approaches to BIM-based quantity calculation [3]: (1) Directly using Revit schedules to calculate component quantities and export them as Excel files, utilizing the quantity statistics function of BIM software directly. (2) Establishing Application Programming Interfaces (API) between BIM-related software and cost budgeting software to extract data from BIM and interface with cost estimation software, such as Guanglianda and Luban software. Guanglianda uses the GFC plugin to export BIM models into

GFC files, which are then imported into Guanglianda GCL software to generate quantity reports using Guanglianda' s calculation program. Luban software similarly imports BIM models into its own platform. (3) Using Open Database Connectivity (ODBC) to access BIM databases, with BIM software as the integration object. For instance, Xindian Bimuyun and ISBIM software are developed directly on the Revit platform, embedding list quota rules to directly access the model database and generate quantity reports according to the rules.

Comparing domestic and foreign engineering quantity calculation technologies, foreign software is more integrated, combining quantity calculation, pricing, contract management, and other project management functions throughout the entire construction process into a single platform. In contrast, current domestic technologies can only solve single problems; quantity calculation software merely implements quantity calculation and cannot interact with pricing and schedule in real-time.

The first two of China' s current three BIM-based quantity calculation approaches have shortcomings: (1) Revit software' s built-in algorithms do not comply with domestic engineering quantity calculation rules, making it unsuitable for direct quantity statistics. (2) Using traditional cost estimation software results in data silos, and reusing BIM models often leads to issues such as missing or displaced components during model exchange.

According to our company' s independently developed Smart Construction Platform, which adopts the approach of directly using quantities extracted from the model and then matching them with prices within the platform, both model reusability and the integration and aggregation of engineering quantity data with price data are ensured. This approach is more similar to foreign technologies, forming cost control and cost management during the construction phase based on 5D-BIM technology. Therefore, this study adopts the use of Revit quantity calculation plugins to implement BIM-based engineering quantity calculation.

2 Comparative Study of BIM-Based Engineering Quantity Calculation Software

Through a comparative study of the three BIM-based engineering quantity calculation methods, this research validates the technical approach of obtaining physical engineering quantities that comply with calculation rules from BIM models and matching them with list codes to output divisional work quantity lists, measure project lists, and other information.

2.1 Research on Single Component Engineering Quantity Based on Revit

The engineering quantities of models differ under list and quota calculation rules. According to list specifications, vertical components such as walls and

columns are dimensioned by story height, whereas quota specifications require vertical components to be dimensioned by net height from the bottom of the slab. Based on the "GB50854-2013 Code for Calculation of Engineering Quantity in Building and Decoration Engineering", connection relationships of model components created in Revit are modified according to the different calculation rules of lists and quotas to ensure correct deduction relationships among components, thereby enabling separate quantity calculations for models under different calculation rules.

[Figure 1: see original paper] Research on single component quantities in Revit software. Through Revit's "Join" – "Switch Join Order" command, the priority between components can be changed and component deduction settings can be adjusted to obtain quantities that comply with specification requirements. However, this process is extremely cumbersome in practical engineering applications and cannot meet on-site work demands. For components such as holes smaller than 0.3 square meters and constructional columns, the quantity calculation rules cannot be satisfied; for items that are not modeled, such as formwork, plaster layers, scaffolding, and roof waterproofing, Revit cannot perform measurement.

The engineering quantities of components in Revit models represent their geometric and physical attributes [4]. While the software includes some built-in quantity deduction rules, it cannot guarantee full compliance with calculation rules due to factors such as component modeling sequence and modeling precision, making it extremely difficult to directly use BIM design software for quantity statistics.

2.2 Comparison of Existing BIM Quantity Calculation Software

This paper compares several quantity calculation software, as shown in .

Quantity Calculation Software Name	BIM Integration Level
Guanglianda BIM Quantity Calculation Software	Self-developed platform: Quantity calculation is performed by importing Revit models into Guanglianda's own platform; complex irregular components are not accurately imported
Luban BIM Quantity Calculation Software	CAD platform: Quantity calculation is performed by importing Revit models into Luban's platform; complex irregular components are imported

Quantity Calculation Software Name	BIM Integration Level
Xindian Bimuyun 5D Quantity Calculation	Revit platform: Maps Revit models to quantity calculation models for measurement
ISBIMQS	Revit platform: Maps Revit models to quantity calculation models for measurement

Through comparative research on general engineering cost quantity calculation software, software vendors such as Guanglianda and Luban can ensure data integrity and speed in data exchange between their internal software, but their interoperability with external software is poor, resulting in numerous errors and omissions. Furthermore, the obtained engineering quantities are static; the models do not include time-sensitive cost engineering information such as time data, schedule information, cost information, and material management.

Our company' s cost management approach for the construction phase is primarily based on the business line within our independently developed Smart Construction Platform to achieve automatic output value reporting and summary ledger formation. However, software such as Guanglianda and Luban use proprietary file formats for storage, and this closed data cannot interface with the platform' s database. Therefore, this study adopts the ODBC approach to implement BIM-based engineering quantity calculation.

Comparing Xindian Bimuyun software and ISBIMQS software, both are quantity calculation plugins developed based on Revit software with similar basic functionalities. Through research on detailed quantity calculation formulas, Xindian Bimuyun demonstrates higher accuracy in engineering measurement. The quantities calculated through the Xindian plugin comply with quantity deduction rules. For components that are inconvenient to represent in Revit models but require statistics in engineering cost estimation, such as formwork, scaffolding, and decorative surface layers, the plugin achieves accurate quantity extraction, solving the limitations of Revit software in quantity calculation. The technical roadmap for implementing BIM model-based engineering quantity calculation using the quantity calculation plugin in this study is as follows.

[Figure 2: see original paper] Technical solution for implementing quantity calculation based on BIM technology

2.3 Comparative Study of Model Quantity Statistics Between Xindian Bimuyun and Guanglianda Software

Although Guanglianda' s data is closed and cannot be exported for use, it is recognized as the most mainstream calculation software in current cost estimation work, and its accuracy in model quantity calculation is widely acknowledged.

Therefore, this study primarily validates the calculation accuracy of BIM quantity calculation plugins by comparing quantities calculated by Xindian Bimuyun software with those from Guanglianda. The following specifically takes the B3 floor for physical quantity comparison of various components.

[Figure 3: see original paper] BIM model and Guanglianda model of B3 floor. Comparative research is conducted on detailed models (such as beams, slabs, columns, walls, etc.), simplified models (such as constructional columns, etc.), and non-modeled items (such as decorative surface layers, formwork, etc.).

Engineering quantity comparison table

When solid models are created in Revit software, the error rate for concrete physical quantities of primary structural components is within ±1%. The Xindian quantity calculation plugin solves the problems of automatic deduction relationships that Revit software cannot achieve and non-compliance with quantity calculation rules, enabling accurate calculation of model volume quantities using BIM.

For items without solid models, the error rate for primary structure formwork area is within ±1%, but the error rate for secondary structure formwork area shows relatively large discrepancies. The main reason is that constructional columns in the secondary structure are simplified models; the quantity calculation plugin reads the original model to automatically generate a quantity calculation model before calculating its surface area. Ring beams and lintels are automatically generated models, leading to model errors. The relatively larger error occurs in decorative structure plastering layer quantities, with calculation errors within 4%, primarily due to the complexity of its included surfaces. However, compared with current calculation software and manual decorative quantity calculations on projects, such errors are within an acceptable range for the business department. Therefore, the conclusion is drawn that BIM-based engineering quantity calculation meets the requirements for engineering cost estimation applications.

3 Research on BIM Modeling Specifications Supporting Quantity Calculation

The accuracy of automated quantity calculation most importantly depends on standardized modeling. To analyze and determine the modeling requirements of quantity calculation software for Revit models, the correct methods for BIM component arrangement were studied sequentially according to connection and deduction relationships between components, and BIM modeling rules with quantity calculation functionality were established and confirmed. Our company' s modeling specifications based on engineering quantity calculation requirements were formulated through three aspects: model splitting, model precision control, and standardized component arrangement, ensuring model accuracy through standardized modeling.

(1) **Model Splitting**: Model splitting is hierarchically divided by unit project, floor, and discipline. In floor division, components at their respective elevations are defined and drawn according to actual floor elevations in the project. Mezzanines in the current floor should be built into the current floor and participate in quantity calculation together with the current floor. Components not at the current floor elevation but represented in the current floor' s design and construction drawings, such as raised/lowered slabs and upturned beams, should also be built into the current floor and participate in quantity calculation together with the current floor.

(2) **Model Precision Control**: The precision of BIM components for achieving engineering quantity calculation is designated as LOD300, and components should include attributes such as geometric dimensions and materials. The accuracy of BIM engineering quantity calculation depends on the geometric information of the model' s actual shape; since quantity statistics in projects are generally categorized by grading and then assigned different unit prices, accurate material information must be added to components in the model.

(3) **Standardized Component Arrangement**: This study proposes standard specifications for model establishment at the component level for divisional and subdivisional works: 1) For standardized model naming, modeled components generally need to be separated by type, specification, and material, with component type names following construction drawing nomenclature; 2) Standardized model arrangement refers to regulations during model establishment that certain component types whose attributes cannot be clearly defined, such as trestles, supports, and guide walls, should be represented using other types of families; 3) The method of model arrangement is standardized, for example, slab openings should be arranged as slab openings rather than through slab edge editing. When components overlap, the connection relationships between various components are clearly defined to ensure that quantity calculation software can achieve automatic deduction without manual adjustment.

4 BIM-Based Engineering Quantity Data Sharing Technology

Based on the specific definitions of physical quantities for divisional and subdivisional works in project engineering budgets, the model attribute information that needs to be exported from BIM models is defined to standardize engineering quantity output and interface the list quantities with the business section data in our company' s developed Smart Construction Platform, realizing the application of BIM technology in engineering cost estimation.

The engineering quantities from Revit models are formed into report statistics and linked with the Smart Management Platform. Since report statistics can

be diverse, it is ensured that the statistical content is sufficiently complete and properly formatted, meeting the requirements of cost engineering for quantity statistics while also being associable with models in the platform. The statistical method is primarily based on model classification by unit project, floor, discipline, and component level, with the statistical content including both model component data and engineering quantity data.

(1) **Matching Lists with Models**: Revit-based quantity calculation software generally includes built-in national and provincial quota databases. Before performing quantity calculation on Revit models, Chinese list types should be set first. Based on Xindian Bimuyun software, the process for matching lists with models is summarized as shown in Error! Reference source not found.

The specified output engineering quantity lists comply with China' s national standard "Code of Bills of Quantities and Valuation for Construction Works" (GB50500-2013) and other construction quota regulations regarding building component classification, coding, and engineering quantity calculation rules [5]. Each engineering quantity list item supports editing of calculation formulas, which encompass component geometric shapes, elevations, dimensions, and engineering attributes. By copying practices, components of the same type are assigned the same engineering quantity list code.

(2) **Engineering Quantity Output Exchange Standard**: Model engineering quantities are output in a standard format, as shown in . They are entered into our company' s independently developed Smart Management Platform in Excel format, primarily by automatically establishing relationships between BIM model components in the platform and list codes in budgets through corresponding ElementIDs and attribute information for each component.

Through the software' s built-in statistical report classification, it is divided into two major categories: engineering quantity reports and indicator reports. The exported table contains 5 columns, similar to the preparation requirements for divisional work quantity lists, including item code, item characteristics, quantity, unit, and group code.

The table below shows the corresponding content: concrete strength grade, formwork (wood) list, noted in volume list, items at the list end cannot appear simultaneously, only one item.

Engineering quantity output exchange standard

5 Application Verification

[Figure 4: see original paper] Example of exported quantities. The background project for this study is the Shanghai Rail Transit Network Operation Command and Dispatch Building, with a construction land area of 10,669.3 square meters. The project adopts a concrete frame-shear wall structure, with steel structure

used for the large spaces in the top two floors. The project is a high-rise building with nine above-ground floors and three underground floors. Using BIM models to calculate quantities for primary structure, secondary structure, and partial decoration, and comparing them with traditional quantity calculation methods, it is concluded that under standardized modeling conditions, BIM-based engineering quantity calculation results can be used in project budgets. Furthermore, the physical engineering quantity data obtained through BIM calculation can be exported according to divisional work lists and entered into the enterprise project Smart Management Platform.

This project research validates the integration of BIM-based engineering quantities with the business department' s output value reporting work. Currently, cost engineers on projects generally use Excel as a tool for estimation and budgeting, requiring extensive form filling each month—work that is fragmented and cumbersome. In contrast, our company' s independently developed Smart Management Platform collects actual construction data from projects, such as planned progress, actual progress, winning bid budgets, and subcontract agreements, and enters it into the Smart Construction Platform. With one click, output value reports and subcontract costs are generated. Construction ledgers are automatically counted, organized, and summarized after report submission, forming structured and systematic ledger records that replace the repetitive calculation, review, and summarization work of cost personnel in periodic cost control, truly achieving automated and intelligent engineering cost management with BIM technology and saving practitioners' time and energy.

[Figure 5: see original paper] Business management interface of our company' s Smart Construction Platform

6 Research Summary

This study aims to explore the suitability and feasibility of applying BIM technology in existing cost management workflows [6], conducting theoretical and empirical research on BIM' s core modeling technology and model deduction relationships, leading to the following conclusions:

(1) Specifications for Revit modeling were proposed to guide the correct establishment of models according to quantity calculation requirements, establishing corresponding work modes, technical standards, and guidance schemes to change the current situation where cost practitioners spend substantial time on engineering quantity calculation.

(2) Automated engineering quantity calculation was achieved through the use of quantity calculation plugins. By comparatively testing calculation results of Revit software for components under different modeling conditions and analyzing deduction rules, the accuracy of BIM-based quantity calculation was realized, solving the problem of limited modeling capabilities in BIM software.

(3) By using the built-in list library of the quantity calculation plugin to automatically assign list codes to component physical quantities, matching them with the quota library and comprehensive unit prices in our company's developed Smart Platform, data sharing was achieved. Various output value and ledger reports can be generated with one click, truly saving cost engineers' time.

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Note: Figure translations are in progress. See original paper for figures.