INTELLIGENT GENERATION OF BILL OF QUANTITY FROM IFC DATA SUBJECT TO CHINESE STANDARD

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ABSTRACT: In the current way for construction cost estimating by using application software in China, the generation of bill of quantity usually needs plenty of manual work, because the design results cannot be used directly. BIM (Building Information Modeling) technology has provided a potential approach to generating bill of quantity more efficiently by utilizing the computable and reusable information which is available from the 3D design results. However, while several commercial application software have already existed in foreign countries, no BIM-based software in this aspect has been developed in China. In addition, the existing BIM-based application software cannot be directly used in China because they do not support Chinese standards. In this paper, through analyzing the related Chinese standard, a discrimination model for bill of quantity (short for BQ) items was established and the corresponding rule database and semantic database were created. Then the IFC-based discrimination model for BQ items was established and the mechanism of intelligent generation of bill of quantity from IFC data was formulated. Finally the mechanism was programmed and verified through an actual project. As a conclusion, the established mechanism can not only be applied to the development of BIM-based construction cost estimating application software subject to Chinese standard, but also can be referred to develop IFC-based construction cost estimating application software for different countries.

Keywords: *Cost Estimating, Building Information Modeling, IFC Standard, Bill of Quantity, Chinese Standard*

1. INTRODUCTION

With the development of market economy, the bill of quantity (BQ for short hereafter) method which is internationally used has become a standard in construction cost estimating for tendering in China during the past decade. As the foundation of the BQ method, the quantity take-off for generating bill of quantity plays an important role in tendering and bidding, progressive payment and final accounting. It is said that about 50% to 80% of effort for cost estimating is spent on the quantity take-off in practice now. Due to the vital role of tendering for construction firms, the efficiency and accuracy of quantity take-off is one of the main focuses to improve construction enterprises' competitive power [1].

So far, several quantity take-off application software have been developed by Chinese vendors supporting the BQ method. These applications have been used in practice in China and have improved the efficiency and accuracy of the generation of bill of quantity to a certain extent. However, in order to generate bill of quantity, the estimators still have to read the shop drawings and build the 3D models after classifying the building products and assigning their properties manually [1]. As a result, plenty of manual work is still necessary because the design results cannot be used directly.

BIM (Building Information Modeling) technology has provided a potential approach to solving the problem. BIM is designed to integrate the project information for the stakeholders of building to share based on 3D digital technique [2]. As a major data standard for BIM, the IFC (Industry Foundation Classes) standard published by the IAI (International Alliance for Interoperability) plays a very important role in the process, since it is now a mainstream standard for sharing data throughout the building lifecycle, globally, across disciplines and applications in the AEC/FM industry [3]. Accordingly, if the design results are saved as IFC data, the information can be shared during the building lifecycle, including cost estimating. At present, several BIM-based construction cost estimating application software have been developed to improve the efficiency of cost estimating in foreign countries. However, due to the localization of standards, these applications can hardly be used in practice in China [1].

This paper firstly establishes a discrimination model for the BQ items and the corresponding rule database and semantic database based on the Chinese standard, and then establishes the IFC-based discrimination model for BQ items. Finally, the mechanism of intelligent generation of bill of quantity from IFC data is formulated and verified for construction cost estimating subject to Chinese standard.

2. THE DISCRIMINATION MODEL FOR BQ ITEMS BASED ON THE STANDARD

In China, the Code of Valuation with Bill Quantity of Construction Works (short for the standard hereafter), which was firstly published in 2003 and revised in 2008, provides the unified rules for classifying and determining the BQ items in the BQ method [4]. At present, though the BQ method is used in practice in China along with the quota method, in most cases it is required that the BQ method is used and the tendering/bidding files comply with the standard [5]. Due to the complexity of the problem, as a start to tackle the problem, this paper takes reinforced concrete construction projects that are widely used in China as an example.

2.1 The classification and coding system of the standard

The classification and coding system of the standard is based on the division-items projects. Each division-items project is expressed by nine numbers belonging to fourth levels. The first two numbers as level 1 represent the category of the project, e.g. the construction project, the decoration project, the equipment installation project. The third and fourth numbers as level 2 represent the category of the work in the project, e.g. the construction project includes the earth-stone work, the pile-foundation work, the concrete work, etc. The fifth and sixth numbers as level 3 represent the subcategory of the work, for example, the concrete work is divided into the cast-in-place/precast concrete foundation, column, beam, wall, etc. The last three numbers as level 4 represent the division-items which divide the subcategories in more detail [4]. In practice, three more numbers are added to make further division according to the eigenvalue of the building products. Figure 1 shows the classification and coding system of the standard by using cast-in-place concrete column whose cross section is rectangle as an example.

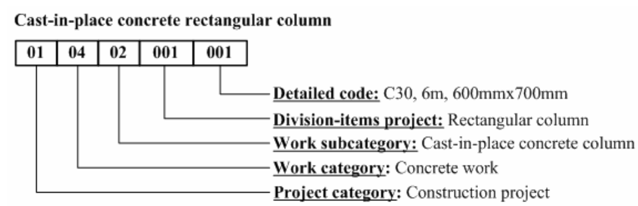

Figure 1 Example of the classification and coding system of the standard

When generating the bill of quantity of the design results, it is needed to identify and extract useful information from the building products to determine the BQ items according to the standard. However, although the standard facilitates human engineers to extract useful information from the design results, several problems need to be solved before the computer is employed to generate bill of quantity.

(1) Expressing the standard for the computer to utilize

In order to generate bill of quantity intelligently, the standard should be expressed in a structured form so that it can be built in computer programs.

(2) Accommodating the semantics of the design results

The descriptions of the design results may not be expressed using the terms in the standard because of the designer's preference, localization, etc., which may cause the semantic problem for the computer to process. For example, the description of "cast-in-place concrete" in the standard may be described in other forms, i.e. common form, shortened form, or even the in different languages. Though IFD (International Framework for Dictionaries) has been suggested by the IAI to solve the problem [6], it has not been established in China.

2.2 The discrimination model for BQ items

Through in-depth analysis on the standard, it is found that the BQ items of a building product could be uniquely determined for building construction projects as long as the five aspects of information, i.e. product type, geometry, material, detailed type and construction issue, are available. Thus, they are called the discrimination information for BQ items. Among them, the product type represents the type of the building products, e.g. wall, beam, slab, column; the geometry represents the shape of cross section of the building products, e.g. rectangular column, arc-shaped wall; the material represents the material used to form the building products, e.g. concrete, brick, wood, steel; the detailed type represents more detailed division of the type of the building product, for example, beam can be divided into general beam, ring beam, lintel, etc.; the construction issue represents the construction method of the building products. Indeed, each BQ item can be determined by less than or equal to five aspects of information as above-mentioned depending on the building product. For example, the BQ item "cast-in-place concrete rectangular column" is determined by three aspects of information, i.e. the product type information is "column", the geometry information is "rectangle", and the material information is "cast-in-place concrete". More examples are shown in Table 1. Based on the above analysis, the information for all BQ items of the standard are established and stored in the discrimination database for BQ items (the rule database for short hereafter).

In order to solve the semantic problem of the design results, the terms are extracted from the standard as standard descriptions; meanwhile the other forms of descriptions that are used in practice are collected and stored in database. Accordingly, the semantic database for the design results is established. Several examples are shown in Table 2.

Based on the two databases, the discrimination model for BQ items based on the standard is established as shown in Figure 2. The model is the basis of intelligently generating bill of quantity subject to the standard in China.

Table 1 Examples of BQ items in the rule database

Code	Name	BQ items discrimination information				
		Product type	Geometry	Material	Detailed type	Construction issue
010201003	Concrete perfusion pile	Pile	——	Concrete	——	Perfusion
010402001	Rectangular column	Colum	Rectangle	Cast-in-place concrete	——	——
010403004	Ring beam	Beam	——	Cast-in-place concrete	Ring beam	——
010408001	Post-cast strip	Other	——	Cast-in-place concrete	——	Post-cast
010409002	Non-rectangular column	Column	Abnormity	Precast concrete	——	——

Table 2 Examples of records in the semantic database

No.	Standard description in Chinese	Description 1 in Chinese	Other descriptions in Chinese	Description in English
1	柱	柱子	…	Column
2	矩形	长方形	…	Rectangle
3	现浇混凝土	砼	…	Cast-in-place concrete
4	带形基础	条形基础	…	Strip foundation
5	挖土方	土方开挖	…	Excavation

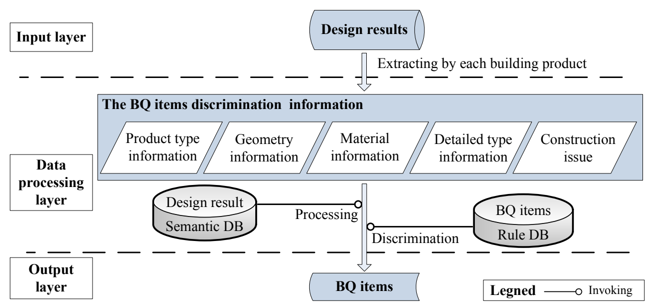

Figure 2 Discrimination model for BQ items

3. ANALYSIS ON INTELLIGENT GENERATION OF BILL OF QUANTITY FROM IFC DATA

The IFC standard, which currently is the most comprehensive and detailed international standard of BIM, is divided into four bottom-up layers, i.e. resource layer, core layer, interoperability layer and domain layer, and each layer consists of a number of modules which further contains various entities, types, enumerations, rules and functions. Among them, the entity is the information agent to describe the information of the building products, while the types, enumeration, rule and function are defined to express the properties of entities and to provide additional constraints and methods for the properties [5]. In this paper, the discussion on the IFC standard will be based on IFC2x3 final version.

The IAI has made great effort to promote the IFC standard for information sharing throughout the building lifecycle, and currently more than 20 vendors of application software are supporting the IFC standard, e.g. Autodesk Revit, Graphisoft ArchiCAD [7].

3.1 The IFC-based discrimination model for BQ items

To extract the discrimination information for BQ items from IFC data, the expression of the five aspects of information as discussed above should firstly be identified in the IFC standard. Because the construction issue is not included in the design results, only the other four aspects of information are focused. The established IFC-based discrimination model for BQ items is shown in Figure 3.

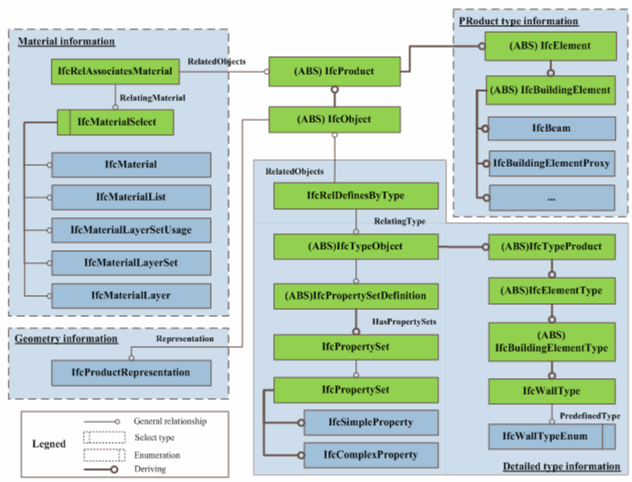

Figure 3 IFC-based discrimination model for BQ items [8]

In the model, the product type information is described by using the entity *IfcBuildingElement* inheriting from the entity *IfcProduct*, while the derived entities of *IfcBuildingElement* are actually used to describe various types of building products. However, the pre-defined types of building products can not cover all the types contained in the BQ standard, thus the entity *IfcProxy* can be used to describe the extra types. The geometry information is described by the entity *IfcProductRepresentation* which acts as the "Representation" property of *IfcProduct*. The derived entities and their properties of *IfcProductRepresentation* define many kinds of geometry representation, i.e. solid model, bounding box, Brep, which can be used to calculate the shape of cross section of building products. The material information is described by five kinds of material descriptions which are included in the select type *IfcMaterialSelect* as shown in Fig. 3. The entity *IfcRelAssociatesMaterial* is used to assign the material to building products. The detailed type information can be described either by the pre-defined enumerations which act as the "PreDefinedType" property of the derived entities of the entity *IfcTypeObject*, or by using the entity *IfcPropertySet* that holds dynamically extensible properties which are described by using the entities *IfcSimpleProperty* and *IfcComplexProperty*. However, the pre-defined enumerations and property sets cannot cover the detailed type defined in the BQ standard.

3.2 Analysis on the completeness of the IFC standard for expressing the discrimination information for BQ items

According to the discussion above, the representation of the discrimination information for BQ items by using the IFC standard can be divided into three cases, i.e. information can be directly expressed (such as most types of the building products, the material information, etc.), information expressed by processing IFC data (such as process geometry representation in IFC data to express the shape of cross section), and information can only been expressed by extending the IFC standard through *IfcProxy* or *IfcPropertySet* (such as several types of the building products, the detailed type information, etc.). For the first two cases, the established semantic database is necessary because of the semantic problem in the design results. For the third case, the research on the extension of the IFC standard for construction cost estimating in China has been carried out to suggest the IAI to add the extension into the IFC standard in order to solve the problem [5].

4. MECHANISM OF INTELLIGENT GENERATION OF BILL OF QUANTITY FROM IFC DATA

Based on the discrimination model for BQ items and the IFC-based discrimination model for BQ items, the mechanism for intelligently generating bill of quantity from IFC data is formulated as shown in Figure 4.

4.1 Extraction and standardization of the discrimination information for BQ items from IFC data

For each building product in IFC data of the design results, each aspect of the discrimination information for BQ items will be extracted separately as original discrimination information according to the IFC-based discrimination model, and then original discrimination information should be processed to the standard discrimination information for BQ items by using the semantic database.

4.2 Intelligent determination the corresponding BQ item of each building product

If the discrimination information for BQ items is complete and can exactly map to certain record in the rule database, then the first nine numbers of the building product could be uniquely determined; otherwise, additional information should been manually added to the building product. The last three numbers can be added by obtaining the eigenvalue of the building product.

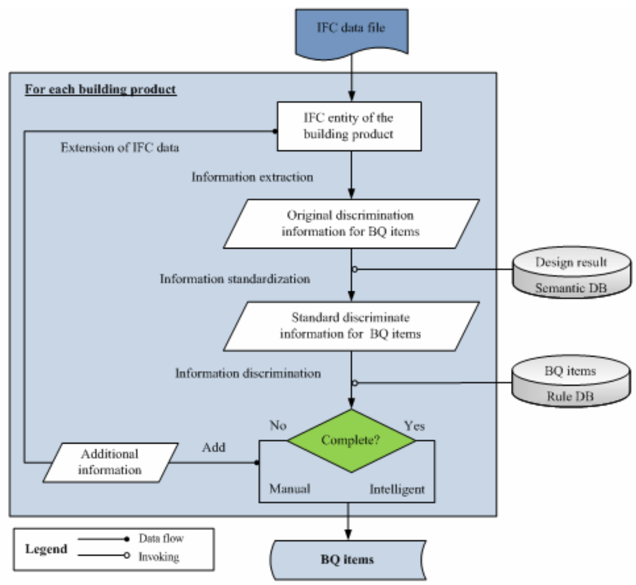

Figure 4 Mechanism for intelligently generating bill of quantity from IFC data

5. QUANTITY TAKE-OFF OF THE GENERATED BQ ITEMS

Theoretically, the bill of quantity could be exactly calculated by using the geometry information of the building products attached to them, and it seems to be only a mathematical matter. However, situations are much more complex in actual process. One reason is that various quantity take-off rules are defined in the standard to prescribe the priority of deduction between the building products when they intersect. For example, the intersection between a column and a beam will be reckoned in the column but not the beam. More examples are shown in Table 3. Another reason is that according to our study on several BIM-based design application software, their deduction rules vary from application to application although their output complies with the IFC standard. For example, no deduction or mistaken deduction is made when building products intersect in some applications. Therefore, specialized processing on the intersection is necessary according to the deduction rules defined in the standard in order to get accurate bill of quantity, as shown in Figure 5.

Table 3 Examples of records in the quantity take-off rule database

Code	Name	Quantity take-off rule
010402001	Rectangular colum	Calculating volume according to design results, the priority of deduction is higher than beam, etc.
010406001	Straight stair	Calculating area of its horizontal plan according to design results, etc.
010403002	Rectangular beam	Calculating volume according to design results, the priority of deduction is lower than column, etc.
010405003	Flat slab	Calculating volume according to design results, the priority of deduction is higher than wall, etc.

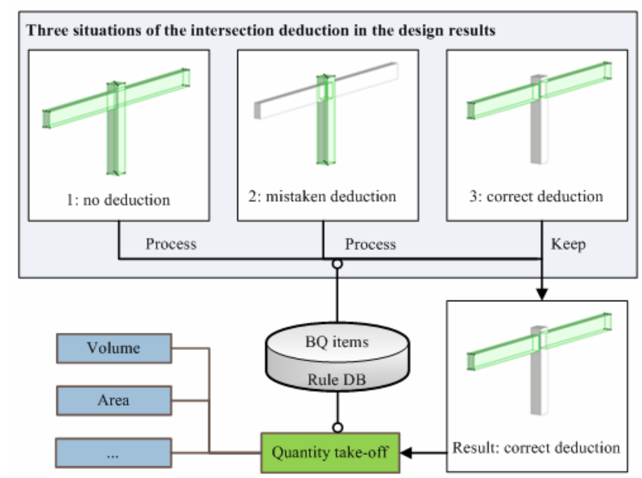

Figure 5 IFC-based quantity take-off according to the standard

6. VERIFICATION

The mechanism of intelligent generation of bill of quantity from IFC data has been applied in the "BIM-Estimate" application software developed by our research group and the application has been successfully used in the cost estimating of a teaching building project. The building is a reinforced concrete structure with 1-floor underground and 6-floors, containing nearly 1300 building products. Autodesk Revit Structure is used to build its 3D model to obtain the design result and the exported IFC file is used as the testing IFC data. The result shows that the percentage of the building elements which can intelligently generate BQ items is up to 67% of all the building elements. All the other BQ items could be generated by manually inputting the information of construction issues, and the quantities could be automatically taken-off, as shown in Fig. 6.

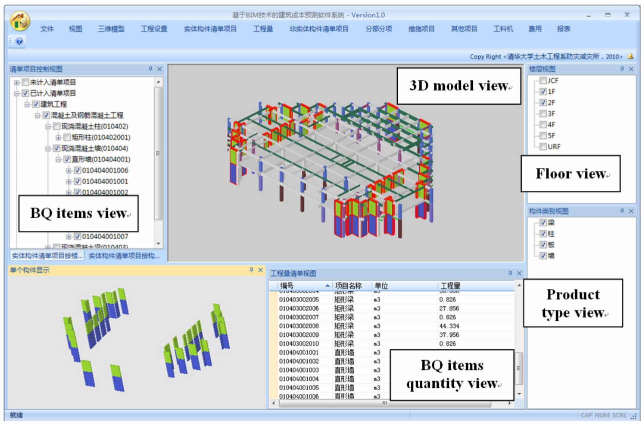

Figure 6 Application of BIM-Estimate in a teaching building

7. CONCLUSION

This paper has established the discrimination model for BQ items and the IFC-based discrimination model for BQ items, and formulated the mechanism of intelligent generation of bill of quantity from IFC data for the tendering/bidding of construction projects in China. The findings of this study are concluded as follows:

(1) The mechanism formulated in this paper can be applied to automatically extract useful information in the design results in order to generate BQ items and calculate their quantities, which greatly saves manual reworks and further improves the working efficiency for construction cost estimating.

(2) The semantic database established in this paper is a feasible approach to solve the semantic problem of the information in the IFC data of design results.

(3) The research not only establishes the mechanism of intelligently generating bill of quantity subject to Chinese standard, but also shows a feasible approach to applying the IFC standard to comply with the standards for different countries.

ACKNOWLEDGEMENT

This study is supported by the National Technological Support Program for the 11th-Five-Year Plan of China (No. 2007BAF23B02).

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