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Cost estimation of structural skeleton using an interactive automation algorithm: A conceptual approach

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Abstract

This paper addresses a new concept for generating bills of quantities (B.o.Qs) using AutoCAD drawings for a building project, which demonstrates the application of Industry Foundation Class (IFC), developed by International Alliance for Interoperability (IAI). The procedure considers types of materials and the structural shapes of the AutoCAD drawings to compute the cost of the structural skeleton elements using interactive automation. The main concept focuses on using layer computation of the AutoCAD drawing after converting it into a drawing interexchangeable file format (DXF). Once the coordinates are detected, it is easier to determine the area and volume for any structural shape, including circles and polygons. The extracting method is a new technique for structural engineers and quantity surveyors to estimate required material for beam, columns, slabs and foundations. The algorithm extracts and recognizes the layers and objects from a two dimensional DXF drawing along with the coordinates information. The results obtained using this technique are more accurate and reliable than manual procedures or any other traditional techniques. In this paper, an automated and interactive procedure for B.o.Q computation is demonstrated. The process involves a user-friendly interface, dynamic linking to the structural drawings and tracking of B.o.Q modifications at the same time.

Keywords: Cost estimation; Industry Alliance for Interoperability; Industry Foundation Class; Interactive; Automation; Structural; Bid construction; B.o.Q; Skeleton

1. Introduction

In civil engineering construction projects, the bidding documents play a major role in winning a project. These documents are the main communication tools for information and instruction, and involve three parts: engineering drawings, specifications and B.o.Qs.

The B.o.Qs are written in a database format to simplify the calculation process and represent the results of mapping the engineering drawings and specifications. This is an automation technique for estimating the cost of structural skeleton elements in a large civil engineering project, mainly in the material estimation of beams, columns and footings. The process involves dynamic changes to the spreadsheet and specification documents accordingly with the engineering drawings. This challenging process involves a dynamic link to the engineering drawings and B.o.Qs while simultaneously monitoring any new modifications of the specifications.

3D drawings for a building include footings, columns, beams, walls, slabs, etc. that are professionally drawn in separate layers to distinguish entities and for calculating areas and volumes. The volume of an individual entity is useful for determining the amount of material to be used and the total project cost by summation of all the entities.

Writing a program that communicates with AutoCAD through a DXF mechanism is a difficult task. The file contains a seemingly overwhelming amount of information, and manual examination of a DXF file may lead to the conclusion that the task is almost impossible. The DXF file can be generated from an existing drawing by using DXFOUT command within the AutoCAD.

The technique used in this research is useful for the products features detection using the geometric and topological data from

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the CAD model. An algorithm that extracts the entities and features based on the geometric properties of the entities implemented similar to the feature recognition used in the manufacturing industry.

2. Preparation of consultant bidding documents

Bidding document preparation generally carried out for a construction project. The consultant office initially receives the scope of the work from the client to provide basic services for the design disciplines, which include but are not limited to:

- Project management and value engineering;
- master site and 3D physical model;
- architecture, building structural and systems engineering;
- site engineering for utilities and civil work;
- landscaping, including interior and exterior;
- irrigation system;
- telecommunications, information systems;
- low-voltage and current systems;
- elevator/vertical transportation specifications, cost estimations and quantity surveying material take-offs (B.o.Qs);
- scheduling of design services;
- acoustics, including base building and special areas (e.g., auditorium);
- audio-visual and special lighting;
- food service/catering system and control;
- intelligent systems/building management.

Fig. 1 shows a sample flowchart of the overall activities in a consultant office for design services.

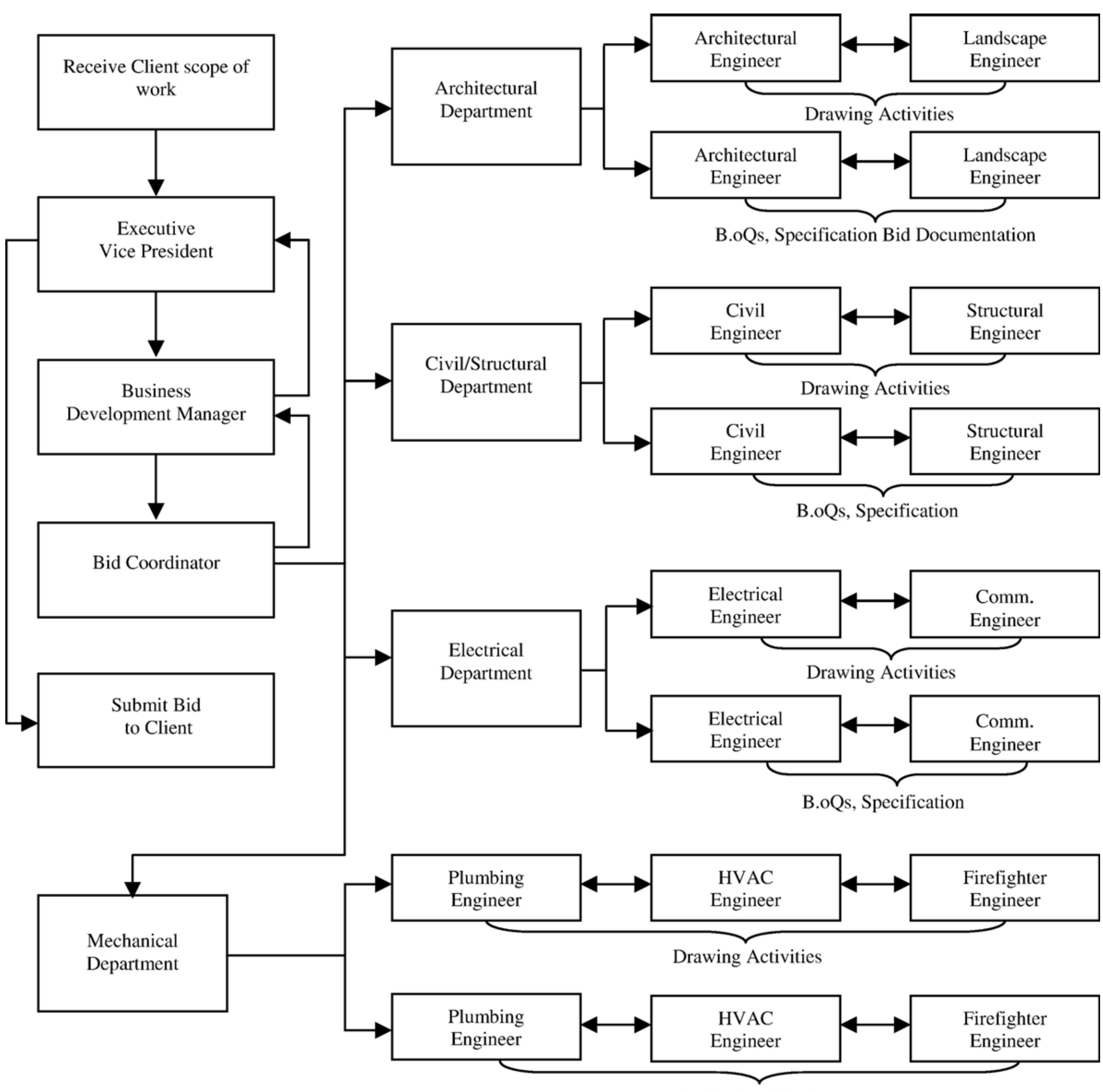

Fig. 1. Bidding document preparation by consultant office for a construction project.

The scope of this work is limited to the architectural and structural drawings, which demonstrate the capability of mapping from these drawing and the B.o.Qs for the take-off quantities.

3. Estimation for bidding documents

The purpose of the bidding department of the contractor's office is to win the bid. After receiving the scope of the work from the client, an overall review is carried out, the technical and commercial aspects are then evaluated using material specifications and quotations from the procurement department. Workmanship, including direct and indirect labor costs estimated and overheads for mobilization, accommodation, transportation, food, etc., estimated for the total project period. During the preparation of a bid, a letter is sent to the client for further clarification of drawings, specifications and B.o.Qs, upon receipt of all the necessary clarifications, the evaluation and bidding processes commence. Finally, the contractor proceeds with submission, otherwise the request is sent for re-analysis. Fig. 2 shows a sample organizational flow chart for a bid prepared by a contractor.

4. Industry alliance for interoperability

The Industry Alliance for Interoperability (IAI) is a global, industry-based consortium for the AEC/FM industry [1,2]. The objective is to make a standard for industry processes of all different professional domains. IAI proposed a standard mechanism for computer applications to share and exchange project information used by all project participants. The IAI's goals are to define, publish and promote a specification so called the Industry Foundation Classes (IFCs) for sharing data throughout the project lifecycle, globally, across disciplines and technical applications [2].

4.1. IFC-based product models

IFC-based product models contain quantity information of the products that could be used for cost estimating. IFC support the

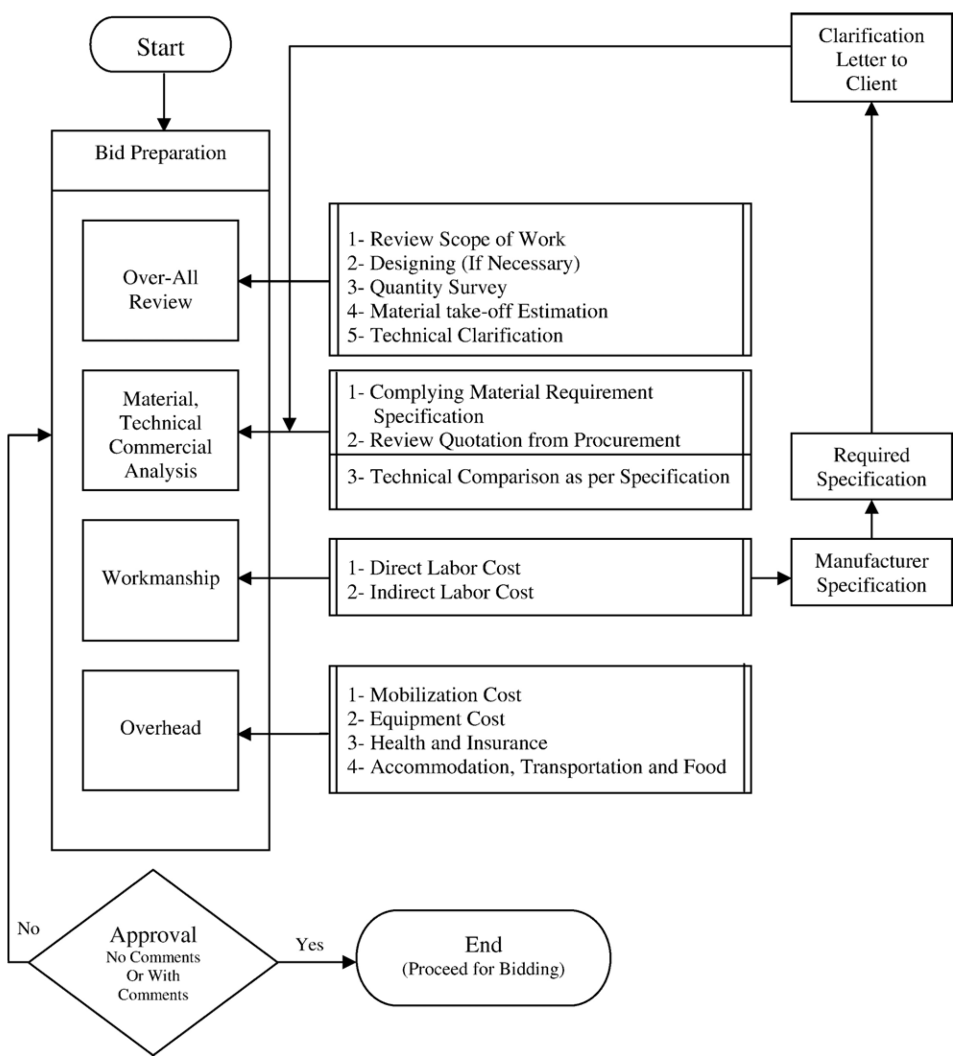

Fig. 2. Contractor organizational flow chart for bid preparation.

cost estimates process and also assist with the maintenance of cost estimation throughout the project life cycle. The model product model contains most of the information needed to create a cost estimate. To support cost estimating processes the IFC's version 2.0 [3] was implemented for initial findings with respect to the suitability. Explicitly represent the estimator rationale for relating product and cost information and the mechanisms to automatically incorporate their affect on construction costs.

There are two options for identifying product features during the estimating process according to Sheryl and Fischer [4]:

- Explicitly represent the product feature in the IFC-based product model.
- Develop reasoning mechanisms to infer the existence of product features from an IFC-based product model.

Although, these features and properties can be extracted from IFC based product model and DXF file as entity collection source, the IFC's do not provide an automated mechanism to technically change the attributes in response to the exchange in product.

5. Cost modeling factors

Cost prediction and estimation are the most essential functions for successful construction planning in civil engineering. It is widely accepted that approximately 70% of the life cycle cost of a product is fixed during the early design phases [5]. There are various methods to determine the pre-cost of a construction by civil engineers and project managers, such as square means and regression lines, but their accuracy is sometimes uncertain because of project complexity and changes in design. These techniques are not recommended for estimation of construction costs because these depend on input data and their results are based on training and the data set.

Tsai and Chang [6] produced a system for geometric tolerance definition using AutoCad [7] applications. Zhao and Ridgway [8] developed a CADEXCATS software package to assist in the selection of tools for turning operations involving COM (component object model)/OLE (object link and embedding) technology and developed a link between AutoCad and the cost estimator programs. AutoCad provides various routes for interfacing, as specified by Ranse [9], including AutoLISP (Auto list processing), ADS (AutoCad development system, C−based), DCL (dialog control language), ARX (AutoCad runtime extension, C+ based), VBA (Visual Basic for applications) and COM/OLE/ActiveX. However, a technique implemented in industry foundation class-based (IFC-based) information servers automatically extracts geometric information from OO–CAD (3D attribute-driven object-oriented computer-aided design) for web-enabled collaborative building design between the architect and the structural engineer.

Pre-design cost estimates are made at an early stage when the design of the project has to be completed. The process involves several estimate iterations in parallel with conceptual or preliminary design, and can be called by other names such as rough, preliminary, order of magnitude (approximate, budget, conceptual or cost target), and feasibility estimates [10]. Cost modeling has been classified into three main models according to the literature [11–13]:

(1) Empirical;
(2) Regression (factor);
(3) Probabilistic (simulation).

The empirical models need basic information for the building in the form of dimensions and descriptions. Examples of these methods are: (a) unit; (b) cubic; (c) floor area; (d) story enclosure; (e) factor; (f) range; (g) approximate quantities.

The estimates require a number of assumptions, so that no method is considered perfect. Therefore, errors can be as high as −30% to 50% according to Bowen and Edwards [14].

6. Interactive automation implementation

3D drawings of a building include footings, columns, beams, walls, slabs, etc., drawn in separate layers to distinguish entities and to calculate area and volume. The volume of an individual entity is vital to determine the amount and cost of material.

Writing a program that communicates with AutoCAD through the DXF mechanism is quite difficult. The DXF file contains a seemingly overwhelming amount of information, and examining a DXF file manually may lead to a lengthy investigation process. The format proposed was constructed with the deliberate intention to simplify the delivery of information without involving the user in the computational process as shown in Appendix A.

The AutoCad drawing is first converted into a drawing eXchange format within AutoCAD or using any third-party conversion tools. In the next step, the layers of the AutoCad drawings are extracted and stored in a temporary file. The interactive automation algorithm executes and extracts the space coordinates from a DXF file. After detecting the entities and some structural calculation for beams, columns and footings, the data are exported to an Excel sheet to generate B.o.Qs for materials. The overall flow of work illustrated in Fig. 3.

This illustrates the work proposed to estimate the weight of reinforced concrete required for multi-layer structures in columns, beams and footings. The white layer represents rectangular and circular footings, the blue shapes represent columns and the green layers represent ground beams. A drawing of foundation plan used for estimation in this research using AutoCAD is shown in Fig. 4.

7. Extracting the layers

The table section of a DXF file contains several sub-tables, each of which contains a variable number of table entries. Each table item consists of a "0" group identifying the item type the same as the table name, such as *LTYPE* and *LAYER*. The layer

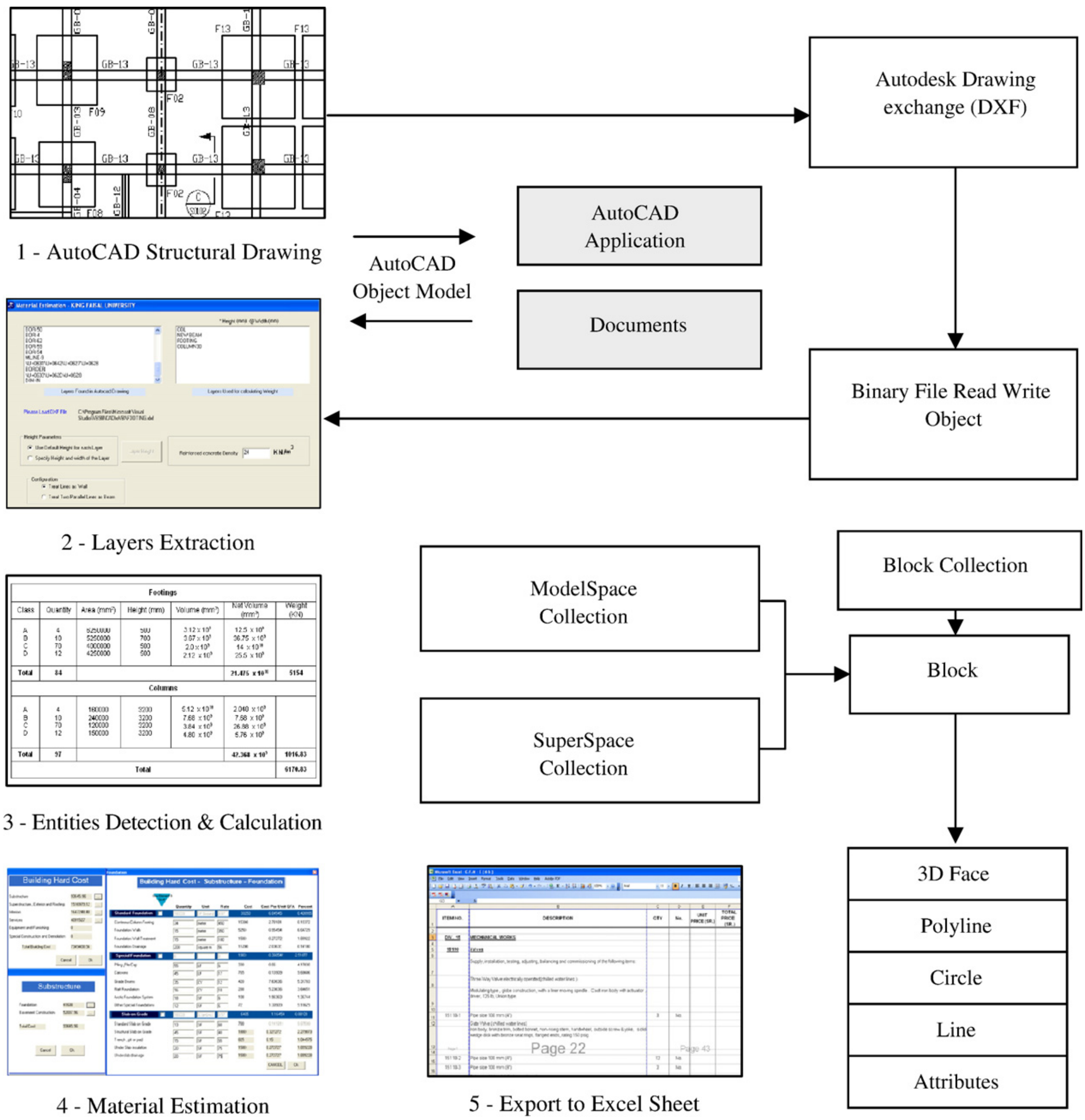

Fig. 3. Procedure implemented to link AutoCAD drawings to the database.

information is stored in the *AcDbLayerTableRecord* section of the DXF file. The end of each table is indicated by a “0” group with the value *ENDTAB*. After extraction of each layer, the results are displayed in a list box. Fig. 5 displays the extraction results and extracted layers that were used for estimation.

7.1. Layer configuration

Estimating the cost of material requires a three-dimensional model but usually a two-dimensional structural drawing is used in practice. This technique does not require to convert the drawings into 3D models, changing layers properties, adding some new layers and migrating existing objects into new layers are much easier than drawing it again. The width of *walls* is also not defined in the drawings, so it is important to set the thickness of walls before estimation.

7.2. Product feature recognition

Feature recognition systems can automatically identify features by using the geometric and topological data from the CAD model. An algorithm that extracts the entities and features based on the geometric properties of the entities is implemented in this research similar to the feature recognition used in the manufacturing industry. Fischer [15] proposed an object-oriented approach for representation of rationale, complex features and constrains represented in implicitly in program code. Sanders and Thomas [16] proposed a statistical model but

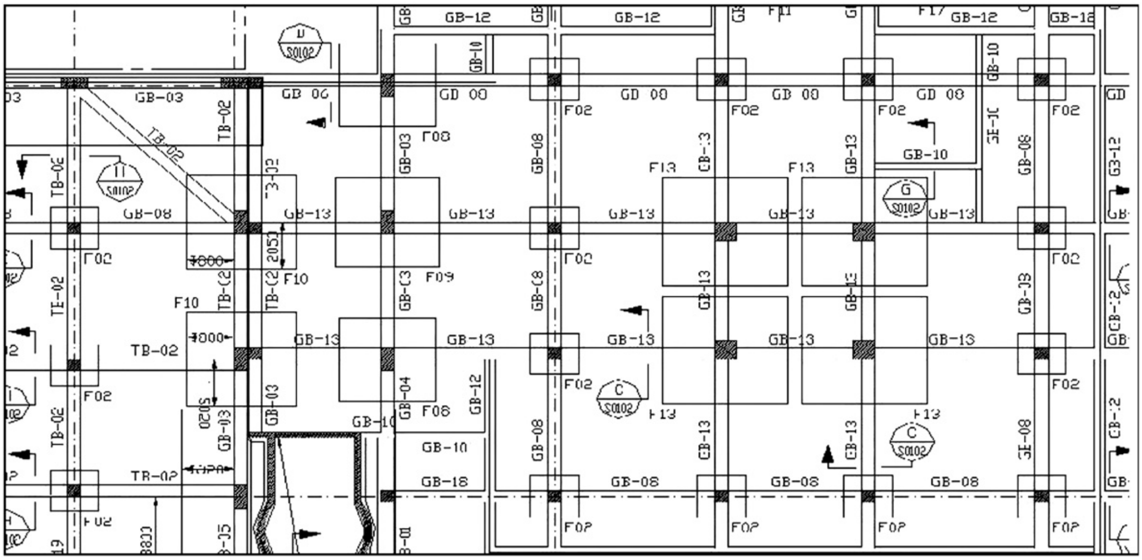

Fig. 4. AutoCAD structural drawing for a building.

it was difficult to extend because the user had to collect the additional information for every new product. Project features also influence project costs. They affect the project as a whole, such as resource availability, environmental effects and site access [17,18].

An instance object of Class-A-Beam-1 Class-A-Column-1 has been initiated for IFC-Beam and IFC-Column as shown in Fig. 6. In the same time an Instance object Class-A-Footing-1 for IFC footing is initiated. It is recommended to extract the products using the default type however the UserDefinedType objects can be derived. The IFC-shape parameters store the height values in Y-height dimension [YDIM].

7.3. IFC extraction for 2D drawings

There are different mechanisms currently used for importing and exporting regarding IFC exchange of a drawing. The 2D drawings exchange is handled by layers and the extracted information represented by layer naming conventions which defines the class of 2D data shown in Fig. 7. The extracted data is not compatible to the IFC model. It is only by visual inspection that coordination of information becomes possible [19].

The research implemented algorithm is an automated mechanism for the extraction of IFC-objects using 2D

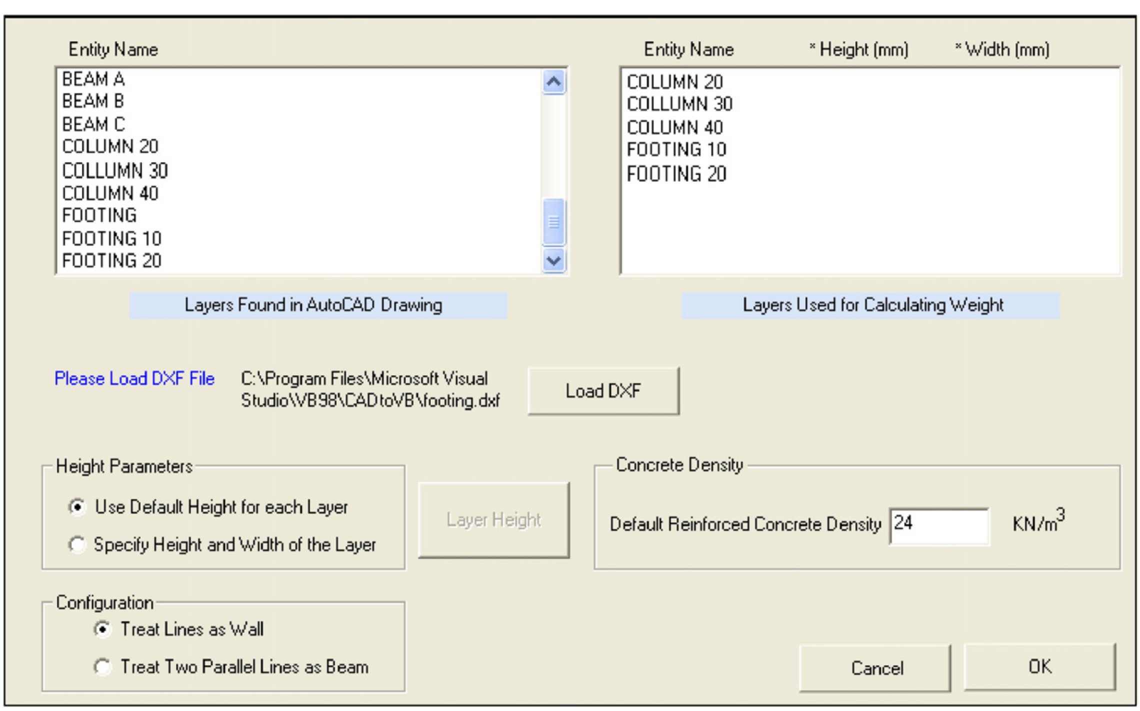

Fig. 5. Extracting layers and setting layer properties.

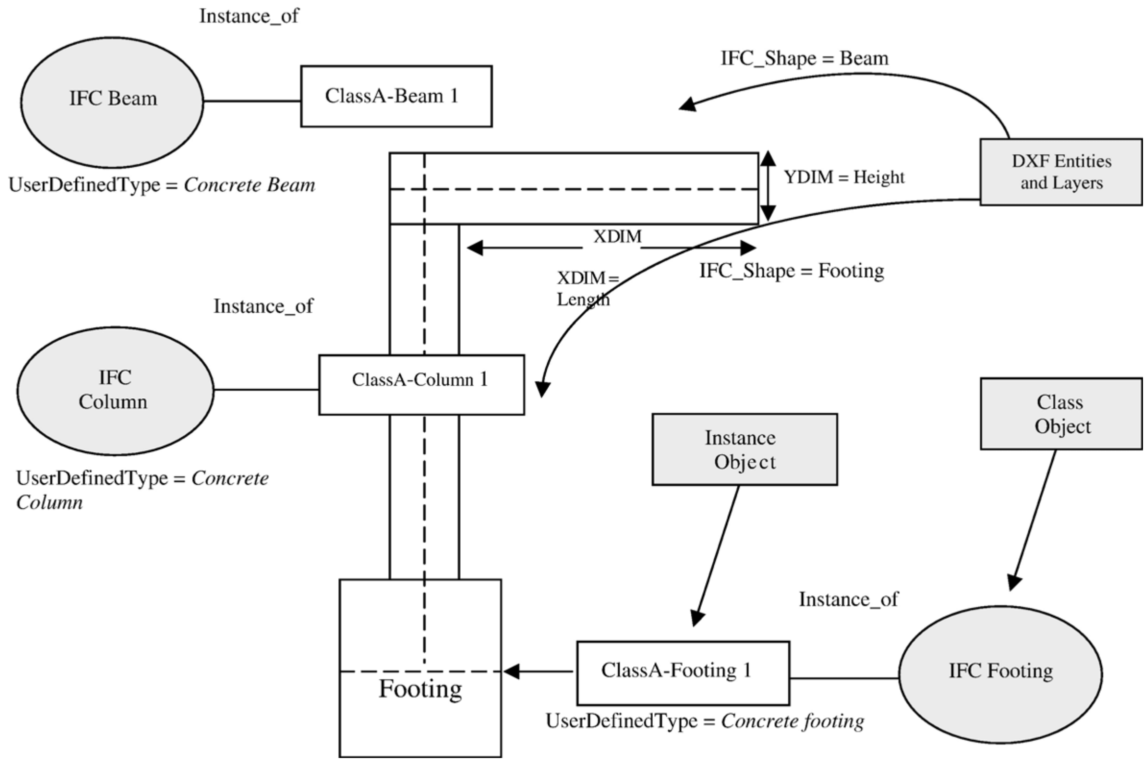

Fig. 6. Beam, column and footing detection in an IFC-based model.

drawings; the extracted IFC exchange objects are transferred automatically from a DXF file, the naming convention or the class is automatically converted into objects in relation to the building model both geometrically in 3D space and recognizing the relations such as the beams, footings and columns. More information is defined within the objects including its dimensions, material, cost and its global unique identifier. The IFC model tracks objects involved in organization to organization exchange. The algorithm extracts the IFC-objects stored in a drawing exchange file provide control for including and excluding required objects and layers for estimation.

The properties of the extracted layers may override or initialized in this phase. Typically, a CAD drawing consists of several layers; it is hard to extract the geometric information needed for structural analysis as mentioned by Chen et al. [20]. A mechanism to provide control over selecting multiple desired layers from the drawing definitely increases the estimation accuracy. The walls, beams, columns and footings should be located on separate layers for estimation of individual elements. It recommended that the *captions* and *dimensions* should define in a separate layer in a drawing. There is an option in the program to change the reinforced concrete density.

8. Challenges in estimation

It is important to consider the issue whereby a user can draw a beam with a line tool instead of rectangle or any bounded shape. How to classify "two parallel lines" as a *beam* or *two walls*? To overcome this problem, the layer properties

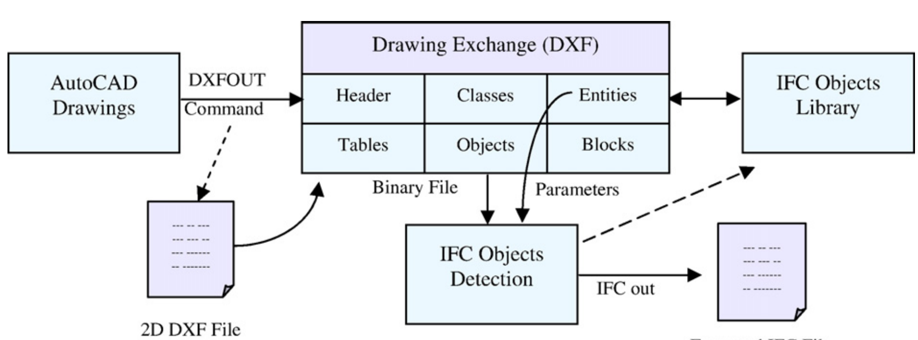

Fig. 7. IFC Extraction using DXF file for 2D drawings.

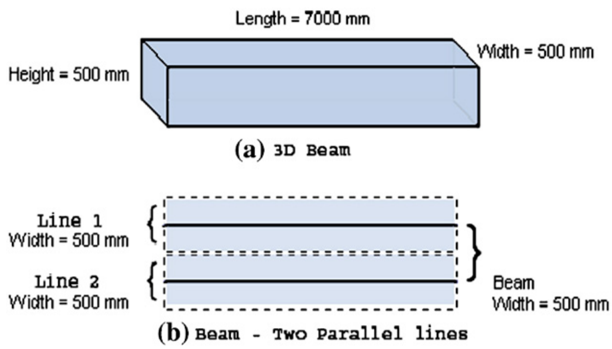

Fig. 8. Classification of a beam and two parallel walls. (a) 3D beam (b) beam — two parallel lines.

must be specified for the shapes on that particular layer to identify them as a *beam* or a *wall*. In the first case, the length of two parallel lines should be reduced to half of the length of both lines, and the length needed to detect objects is reduced to half. Fig. 8a shows the length, width and depth (7000 mm × 500 mm × 500 mm, respectively) for beam illustration. Fig. 8b shows two parallel lines representing a beam; if an estimator adjusts the width of a layer to a particular value ultimately all the objects on that layer acquire that value, resulting in a doubling of the width of the beam. In this example 500 mm + 500 mm = 1000 mm, while the actual width was 500 mm. Total 97 columns were detected and classified into classes A–D according to their size and shapes and are shown in Appendix B.

9. Building hard cost estimation

A user-friendly and interactive menu for estimation is shown in Fig. 9. Building hard cost includes substructure, exterior and interior roofing and furnishing cost. The substructure cost including foundations and foundation walls provided for a comprehensive cost estimation of a project. The cost per unit area and percentage in a project is shown in Fig. 9.

10. Conclusion

A simple building case was proposed to illustrate the procedure involved in estimation of materials by linking the AutoCAD drawing with the B.o.Qs. Cost estimation prior to construction enormously reduces the overall project cost that is the ultimate objective to win a project. The technique implemented provides accuracy and demonstrates dynamic linking between the B.o.Qs and AutoCAD drawings. The risk of overestimation is eliminated if the right tools are used efficiently. The proposed approach is efficient in helping professional builders, contractors, and renovators to quickly and accurately determine the actual structural quantities required for bidding for a project within a user-friendly interface.

Acknowledgements

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Appendix A

Algorithm for Exporting Entities

1- Open DXF File for Input
2- Open Temp file For Output
3- Do Until EOF(1)

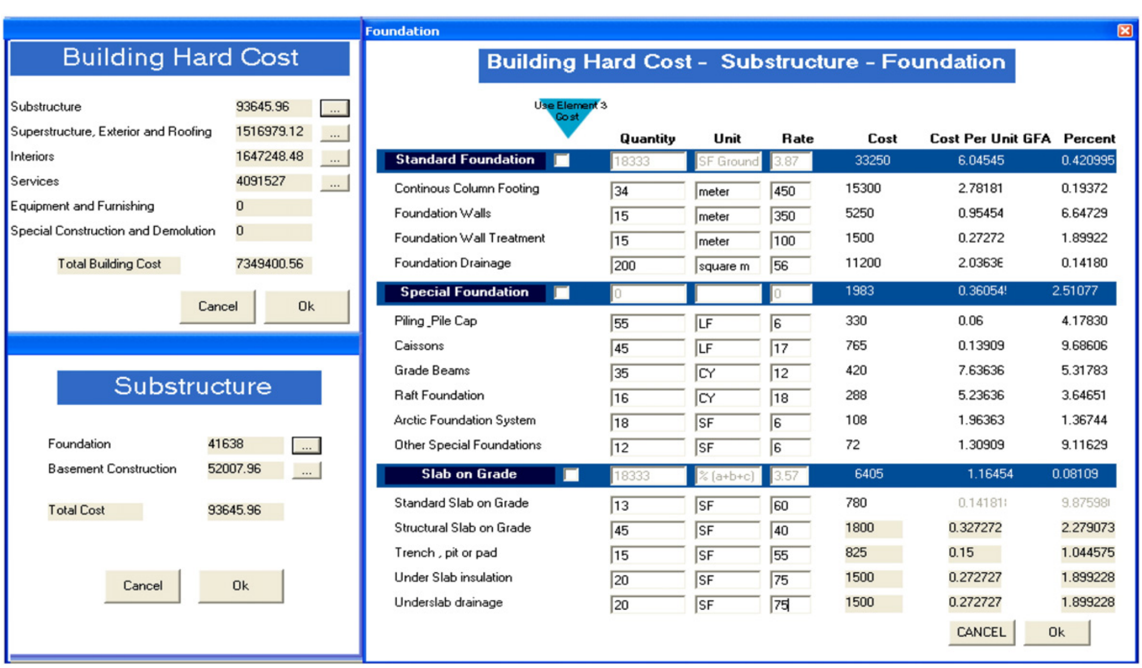

Fig. 9. An interactive interface for the columns and footings estimation.

4- Increment in Pointer
5- Read line and store in variable Myline
6- If Myline = "ENTITIES" Then
7- Increment in Pointer detection
8- Pointer of detection = Current Pointer
9- If Current Pointer >= Pointer of detection Then Store current line into Temp
10- If Myline = "ENDSEC" Then GOTO 3

Algorithm for Detecting CAD Layers

1- Open DXF file for input
2- Do until End of file
3- Read line and store in variable Myline
4- Set pointer to next value
5- If "AcDbLayerTableRecord" present then Increment in Layersfound
6- Set Pointer to current line
7- If Pointer<> 0 Then
8- If Pointer = Pointer + 2 Then (Extract the header)
9- Detected Layer Name = Myline
10- If Myline<> 0 Or Length of Myline >= 2 Then
11- Store Layers in list box
12- Goto 2

Appendix B

Table B1
Auto-generated result for cost estimation of columns and footings

Class	Quantity	Area (mm^2)	Height (mm)	Volume (mm^3)	Net Volume (mm^3)	Weight (KN)
Footings						
A	4	6250000	500	3.12×10^9	12.5×10^9	
B	10	5250000	700	3.67×10^9	36.75×10^9	
C	70	4000000	500	2.0×10^9	14×10^{10}	
D	12	4250000	500	2.12×10^9	25.5×10^9	
Total	84				21.475×10^{10}	5154
Columns						
A	4	160000	3200	5.12×10^{10}	2.048×10^9	
B	10	240000	3200	7.68×10^9	7.68×10^9	
C	70	120000	3200	3.84×10^9	26.88×10^9	
D	12	150000	3200	4.80×10^9	5.76×10^9	
Total	97				42.368×10^9	1016.83
Total						6170.83

Reinforced concrete density = 24 KN/m^3.

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