Estimation of Building Costs Using Geographic Information Systems

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Abstract

In traditional construction cost estimation, quantity take-off is usually performed manually using the design drawings. The traditional method, in general requires a lot of time and effort as several similar calculations are repeated for each item included in the project. In this study an alternative method for construction cost estimation is presented. In the proposed method, geographical information systems (GIS) and computer aided design (CAD) drawings are used to perform quantity take-off. The method is applied to a building project for quantity take-off of concrete, formwork and reinforcement bars. The quantities were calculated by integrating the CAD drawings of the project into the ArcGIS software. The main advantage of the proposed cost estimation system is that it does not require additional data other than CAD drawings, and method can be implemented using existing CAD drawings of the contractor. The method provides an efficient tool for quantity take off and cost estimation of construction projects without requiring additional drawings and cost. ArcGIS also enables 3D visualization of the project rendered from 2D CAD drawing as a result benefits of 3D representation is obtained as by-product at the end of cost estimation. Benefits of the proposed method are discussed along with limitations and future enhancements.

Keywords

Cost estimation, Geographical information system, 3D visualisation, IT in construction

1. Introduction

Determination of quantity take-off of construction materials, labor and equipment in a fast and accurate way has significant importance before the tender stage in order to prepare a proper bid document. In general final design would not be available just a couple of days before the tender because of the scope changes. As this is the case, quantity take-off is recalculated several times during the preparation of bid documents. Apart from this, in order to try different construction alternatives and methods, feasibility of different projects might be desired to be investigated. This requires again an exhaustive quantity take-off work. As the tender documents are prepared within limited time period and under high pressure and stress on the staff, bid preparation task demands high amounts of labor and is prone to personal mistakes.

Quantity take-off is generally prepared by using the printed versions of the Computer Aided Design (CAD) files. However, quantity take-off can be performed by directly using the digital CAD drawings. In this case, not only the quantity take-off procedure will be easier and faster but also the digital CAD drawings will be used more efficiently. As a result the tender preparation staff will have better opportunities to prepare error free tender document.

ArcGIS is chosen for the automated quantity and cost estimation from CAD drawings, since the software can open and edit CAD files and have the capability of construction a relational database. Moreover,

ArcGIS has complementary software ArcScene which can perform 3D visualization. 3D representation has the benefits of easily recognition of the design and possible defects. ArcGIS is widely used Geographical Information System (GIS) software. This study will be a proper and beneficial application of Information Technology (IT) in construction.

GIS is one the technologies that propose several implementations for the construction sector. Cheng and Chen (2002), had developed a system based on GIS, radio frequency transmit technology, and barcodes for monitoring and tracking of prefabricated elements. An automated schedule control and monitoring system had been developed for precast building construction. The system enabled monitoring of the prefabricated elements during; manufacturing, transportation, storing and construction stages. Cheng and O'Connor (1996) developed an automated site layout system for construction temporary facilities (TFs). The system includes a GIS integrated with database management system (DBMSs) which is a new tool to assist designers in identifying suitable areas to locate TFs.

Moselhi and Hassanein (2003) developed a system based on GIS for data acquisition and analysis for highway construction. Seo and Kang (2006) developed a system based on GIS for roadway construction planning. The proposed system provides the planners with an interactive space scheduling function with which the planners can divide 2-D roadway graphic objects into construction stage modules so as to conduct quantity take-off and calculate duration and cost of construction elements.

Bansal and Pal (2007) proposed a methodology using ArcView for storage of descriptive data. The methodology linked safety and the quality control recommendations for the corresponding tasks. Bettemir and Sonmez (2008) proposed a system for the automated cost estimation of dam projects with geographical information systems. The proposed system computes the cost of the material, labor, machine and equipment costs of the construction activities.

2. Data Entrance and the Preparation of Data for the Analysis

In this study, quantity take-off and cost estimation of a frame of two storey building is performed. Digital CAD drawings are opened by ArcGIS and columns, beams and slabs of the building are exported to the ArcGIS media and the data of the third dimension are entered manually.
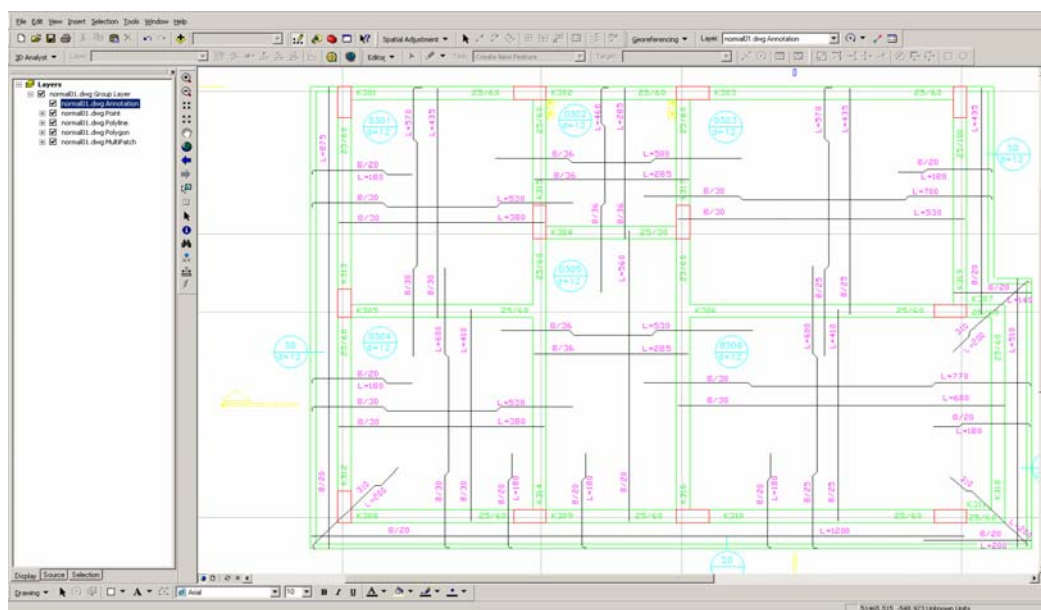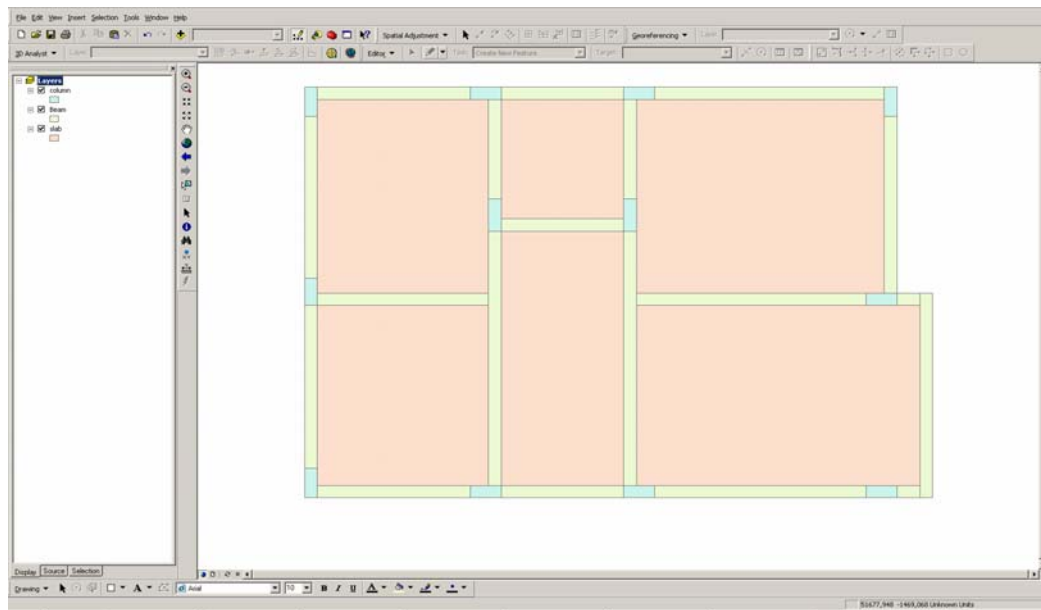

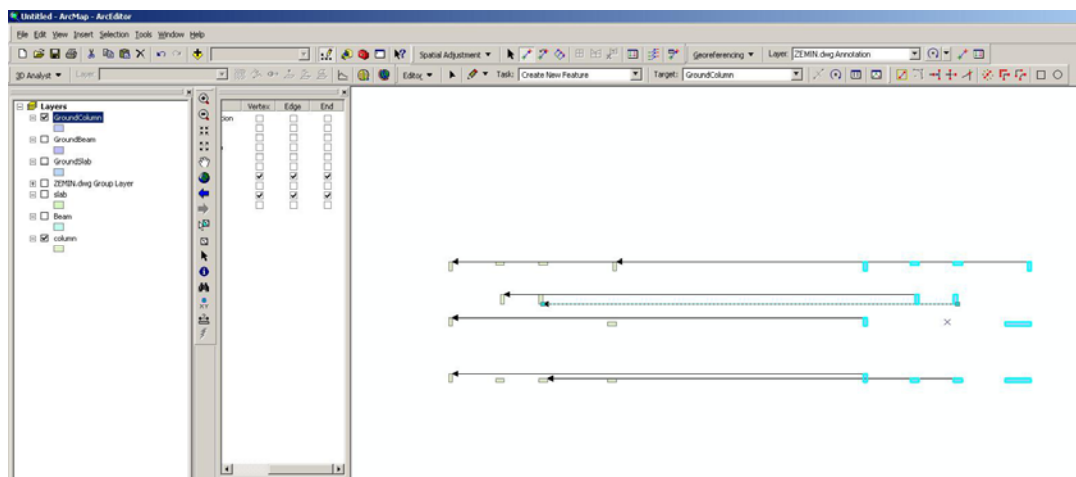**Figure 1: Representation of CAD File on ArcGIS Media**

In Figure 1, the CAD drawing open in ArcGIS media is shown. ArcGIS can open CAD files without any problem and with its *Editor toolbox*, it can edit CAD files. By using the floor plan, columns, beams and slabs of the building are exported to the ArcGIS and saved as *layer*.

Figure 2: Structural System of the First Floor

Structural elements of the building, columns, beams and slabs, are saved in different layers as shown in Figure 2. Perimeters and areas of each structural element is calculated by the command *Calculate Geometry*.
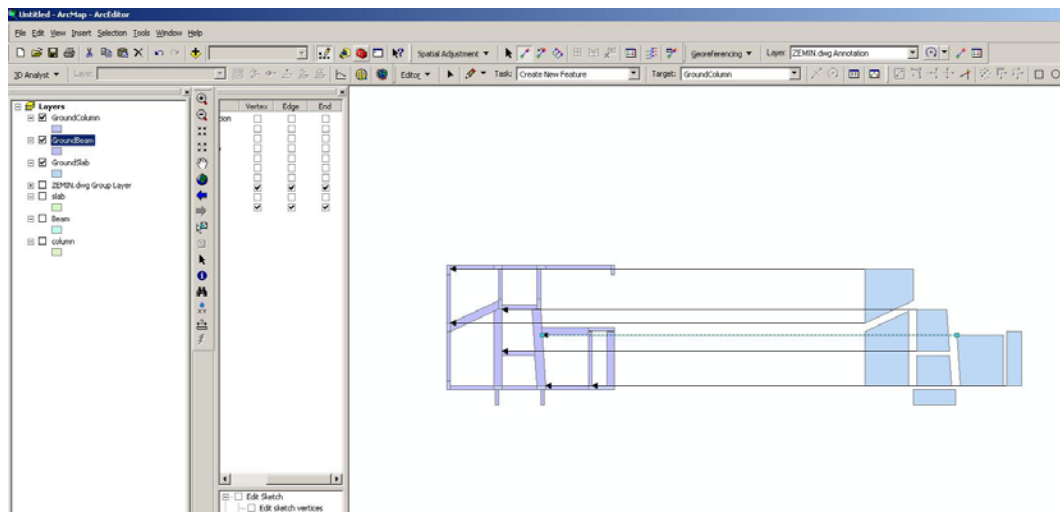
Structural drawings of ground floor are exported into ArcGIS by the same method applied when exporting the first floor. However, because of the drawing style of the technician, two drawings did not coincide, although they are representing the same object whose horizontal positions are exactly the same. The difference is probably caused by the fact that the origins of the defined coordinate systems of the two drawings were not the same.

Figure 3: Common Points used for the Translation of Columns of Ground and First Floors

Layers of the two different floors are moved on to each other by defining common points whose horizontal coordinates are the same. It was known that the scales of the two floors were coincident but only the horizontal coordinates needed to be adjusted. For this reason, only one common point was enough for translation. However, it is known that making redundant observations are essential in order to detect any mistakes during the transformation. By using the *Spatial Adjustment* toolbox, the two floor layers are properly translated.

Before the translation of ground and first floors' structural elements, it can be seen from Figure 3 and Figure 4 that, they do not coincide. This does not cause any problem during the quantity take-off; however it would be impossible to generate a 3D representation of the frame of the building. In order to generate a 3D view, the layers of structural elements of different floors should coincident.

Figure 4: Common Points used for the Translation of Slabs of Ground and First Floors

Snap property is activated and corner points are preferred in order to minimize the possible errors when determining the common points. By doing so, the error sources caused by the operators are minimized. As seen from Figure 3 and Figure 4, there is not any scale change but only translation in x direction. Magnitudes of error are shown in Figure 5. Since the coordinates are local coordinates not the global coordinates, it is not possible to call this translation as rectification. This can only be called as shifting from one local coordinate system to another system.

ID	X Source	Y Source	X Destination	Y Destination	Residual Error		
1	53155,529480	-596,475403	50287,529497	-596,475422	0,000009		
2	53155,529480	-956,475403	50287,529497	-956,475422	0,000011		
3	53515,529480	-866,475403	50647,529490	-866,475414	0,000012		
4	53515,529480	-1146,475403	50647,529490	-1146,475414	0,000010		
5	53815,529480	-1376,475403	50947,529496	-1376,475424	0,000007		
6	54135,529480	-1376,475403	51267,529517	-1376,475453	0,000019		
7	53792,422729	-1036,475403	50924,422745	-1036,475423	0,000009		

RMS Error: 0,000012

Figure 5: Magnitude of Error of the Translation Procedure

Error vectors shown in Figure 5 are accurate enough for the 3D representation and quantity take-off. Unit of the error vectors is cm, and the Root Mean Square (RMS) error is only 0,000012 cm. In addition to this, the residual errors of the common points are distributed normally so that it is clear that no point

contains any mistake. The residual errors are probably caused by the software's precision of the coordinate representation.

With the available data it is possible to do the quantity take-off of the concrete and formwork. In order to perform quantity take-off of rebar, attribute data of rebar is manually entered into the ArcGIS database. If the rebar data were systematically entered during the drawing, it would be very easy to export the rebar data from the annotation layer.

3. Quantity Take-off

In this study, quantity take-off of three items will be performed. These items are: formwork, concrete and rebar. Quantity take-off of concrete is the easiest among the three. It is computed by multiplying the cross section area with height of the cross section.

Figure 6: Computation of Concrete Amount

Computation of concrete amount is shown in Figure 6 by using the *field calculator*. Since the unit of the drawings is in cm, the volume of concrete is computed in cm^3.

Computation of formwork area is a little bit difficult than the concrete. If the formwork area is computed by directly multiplying perimeter and height, than the intersection places of column, beam and slabs would be taken into account unnecessarily. For this reason, it is necessary to subtract voids from the computed formwork amount. Total formwork amount is computed as follows; first of all the perimeter of columns and column height are multiplied and the formwork for the columns is computed. Each beam's both ends intersect with a column or another beam; as a result the void is computed by multiplying the shorter side of the beam with its height. If a beam intersects with another beam, its depth must be equal or less than the beam it intersects.

Formwork of the beams does not cover the top side of the beam but covers the remaining sides. For this reason, the formwork area is computed as by subtracting the shorter sides from the perimeter of the beam and multiplying the remaining part with the beam depth. Since the beams intersect with slabs, the intersection area is computed by multiplying the perimeter of the slab with its depth.

ArcGIS gives the area and perimeters of the polygons, but the software does not give the side lengths of the polygon. Fortunately, the beams are rectangular in shape and by using the area and perimeter of the beams, side lengths can be computed. The formula gives the short side can be represented as;

$$\frac{\frac{perimeter}{2} - \sqrt{\left(\left(\frac{perimeter}{2}\right)^2 - 4*area\right)}}{2} \qquad (1)$$

The formula gives the longer side when the minus sign in front of the square root is replaced by plus sign.

Stirrup and reinforcement bars are computed separately since their cross sectional areas are different. As bended and straight bars' lengths are different they are all stored as separate item in the database.
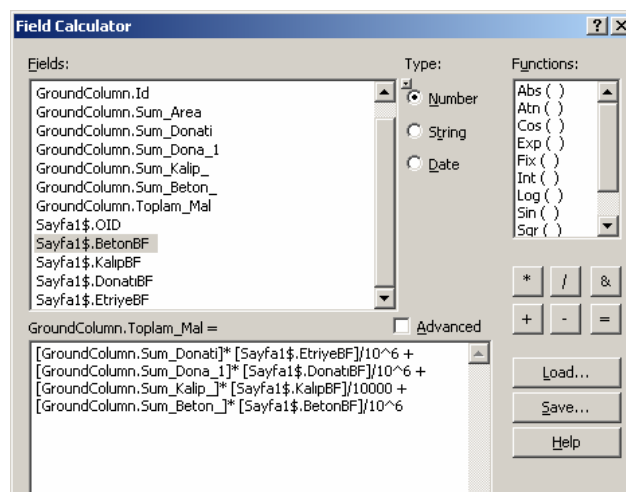

Figure 7: Atrribute Table of Slab Layer

Attribute table of slab layer is shown in Figure 7. Reinforcement data is entered to the related columns and total length of the reinforcement steels are computed for each slab in cm. Moreover, concrete and formwork amounts can be seen at the related columns of the attribute table. The next step is the calculation of the costs of the items by multiplying the quantities with unit prices.

Unit prices of the materials are prepared by MS Excel and exported to ArcGIS. The exported unit prices are joined to the summary tables of the layer files whose costs will be computed. This is executed by the *join* command of the database management software. In Figure 8, summary table of the slab layer is shown after the join operation with the unit price data. The total quantities can be multiplied with the unit prices and the total cost of the slab can be computed.

Figure 8: Summary Table of the Slab after the *Join* Operation

Computation of total cost of the construction by using *Field Calculator* is shown in Figure 9. Entered formula is saved and it can be reused. The divisions are for the unit conversion.
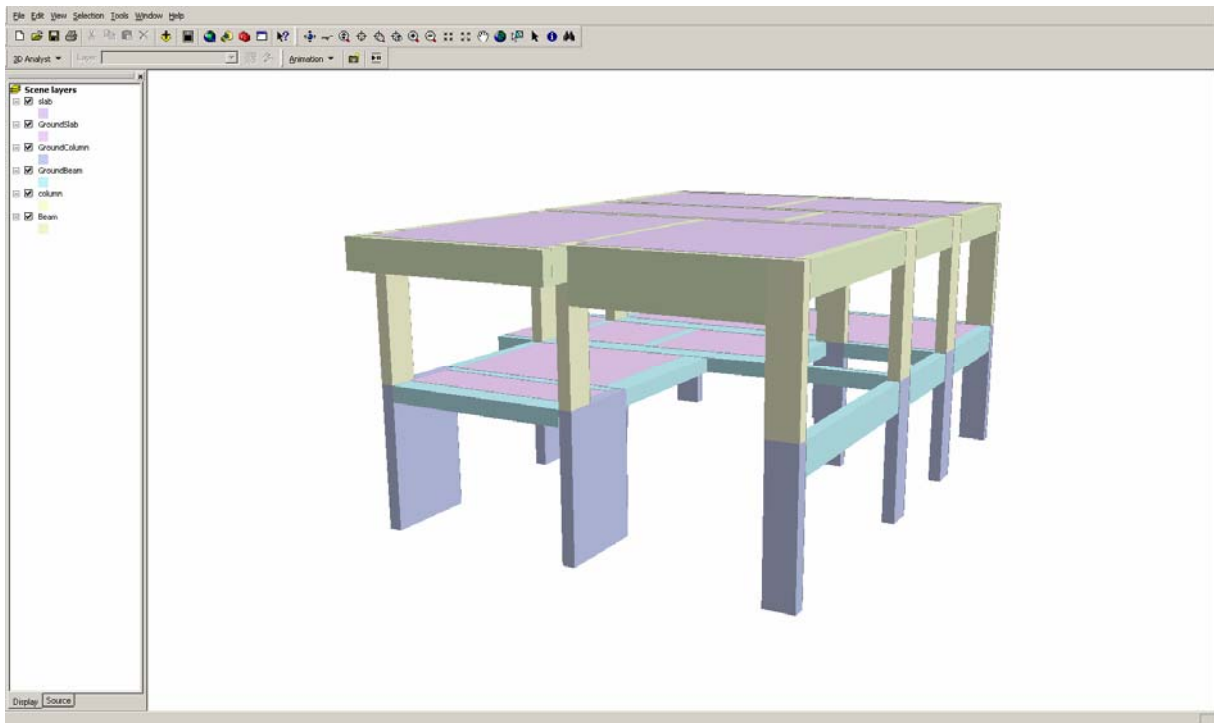

Figure 9: Computation of Total Material Cost

Total cost of the concrete, rebar and formwork of the slabs of the first floor is computed as 3142,44 TL as seen in Figure 10.

Figure 10: Total Cost of the Slabs of the First Floor

4. 3-Dimensional Representation

3-Dimensional representation is performed by the ArcScene software which is embedded into ArcGIS. Layer files of ground and first floors are opened and height values of the structural elements are extracted from the *Height* column of the attribute table. Height values are entered to the *extrusion* tab and the elevations of the structural elements are entered into *base heights* tab.

Figure 11: 3-Dimensional Representation

3-Dimensional representation of the structural frame of the building in which the quantity take-off of its concrete, formwork and rebar is performed. The generated image is shown in Figure 11. 3D representation not only provides visualization but also help determining the defects and imperfections of the design. Besides design, 3D representation helps construction planning engineers also. Difficulties of the construction can be predicted more precisely, which is expected to increase the correctness of the duration estimation of the activities. Physical and spatial restrictions of the construction tasks would be determined and synthesized more properly. Consequently, better construction schedule will be prepared and spatial conflicts during the construction will be prevented and possible work accidents will be counteracted.

5. Conclusion

Two storey frame structure's quantity take-off of concrete, formwork and rebar is performed by directly using digital CAD drawing on ArcGIS software. It is expected that this study will be an example to apply automated quantity take-off at the preparation of tender documents step.

In order to perform quantity take-off procedure in a completely automated way, the CAD drawing must be prepared accordingly. Educated and experienced technicians should be employed for the preparation of the CAD files. The column, beam and slab must be drawn in separate layers and coherently. In addition to this, the polygons must be enclosed and there should not be any duplication of a line or polygon.

Using GIS software for the quantity take-off will be more meaningful if there is an earthwork activity in the construction. In this case the, the time savings and the accuracy of the results will be more significant.

6. References

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