Application of Geographic Information System for Preparing the Bill of Quantities of Construction Projects

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Abstract

The information required for construction quantities surveying is not only generated by various participants in different construction phases but also stored in different forms including graphics, text, tables, or various combinations of the three. To report a bill of quantities (BOQ), the project manager has to continuously excerpt information from various resources and record it on papers. Without adequate staff and time, this repetitive and tedious process is difficult for the project manager to handle properly and thus reduces the effectiveness and the accuracy of the quantities surveying process which creates problems during the design, tender, and construction supervision of construction projects for designers and contractors practicing because receipts are based upon actual quantities, such variations have an obvious impact on the contractor's cash flow, once the actual quantities frequently vary from the estimated quantities listed in the BOQ. Hence, automation quantity surveying system has been developed by using GIS to extract the data required for the quantity of different components of any construction project from AutoCAD drawings (spatial data), to report a BOQ after querying, manipulation, and analyzing these data. The system has been implemented on the construction project of Al khawarizmy College at Baghdad University in Baghdad. The main results of using this system are automatic generation a bill of quantity (BOQ) directly from design drawing, with overcome to design changing, accurate, fast, and effective method for estimating the quantities, fewer errors in cost estimating, and better documentation for continuously reusing information in all construction phases. The accuracy of GIS quantities had been proved by comparing these quantities with the quantities of site surveying. Then determining the accuracy percentage (A%) of GIS quantities which equals (98.85%), and the regression line that equals 0.999. These values mean; there are big correlation between the estimated quantities by GIS and the quantities of site surveying.

Keywords: GIS, BOQ.

أستخدام نظم المعلومات الجغرافية لاعداد جداول كميات المشاريع الأنشائية

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الخلاصة

ان المعلومات المطلوبة للمسح الكمي في المشاريع الانشائية تنتج من مختلف المشاركين في مراحل التشيد المختلفة و تكون محفوظة بصيغ مختلفة تتضمن الرسومات أو النصوص أو الجداول، أو قد تكون محفوظة بدمج هذه الصيغ الثلاثة مع بعضها.و لذلك يتطلب أعداد قائمة الكميات (BOQ) من مدير المشروع ان يقتطف المعلومات بأستمرار من المصادر المختلفة و ان يقوم بتسجيلها على الورق. وبدون وقت و عدد موظفين كافي سوف يكون من الصعب على مدير المشروع ان يدير عملية جمع المعلومات المتكررة و المملة بشكل صحيح ،و هذا يقلل من كفاءة و دقة عملية المسح الكمي مما يؤدي الى خلق المشاكل خلال مرحلة التصميم و العطاء و الاشراف خلال مرحلة التشيد للمصمم والمقاول بسبب ان الايصالات المالية تعتمد على الكميات الواقعية و أي اختلاف يسبب تأثير واضح على التدفق المالي للمقاول و ذلك لاختلاف الكميات المنفذة موقعيا عن الكميات المخمنة في قائمة الكميات(BOQ). لذلك قامت الباحثة بتطوير نظام اتمتة المسح الكمي باستخدام نظم المعلومات

الجغرافية(GIS)والذي يقوم باستخراج البيانات المطلوبة لكميات فقرات اي مشروع انشائي من رسومات الاوتوكاد (AutoCAD) (البيانات المكانية)، لأعداد قائمة الكميات(BOQ) بعد استقصاء و معالجة و تحليل تلك البيانات بواسطة نظم المعلومات الجغرافية (GIS) . و لقد طبق النظام على مشروع تشيد كلية الخوارزمي في جامعة بغداد في بغداد و تبلغ مساحة هذا المشروع 5508 متر مربع، و تتكون الكلية من طابقين و 92 قاعة و مرافق اخرى لمختلف الاغراض.ان من أهم نتائج استخدام هذا النظام هي انتاج قائمة الكميات (BOQ) مباشرة من الرسومات التصميمية مع تغطية لجميع التغيرات التصميمية، و بطريقة دقيقة و فعالة لتخمين الكميات، مما يؤدي الى اقل اخطاء في تخمين الكلف و انتاج وثائق يمكن استخدامها في جميع مراحل التشيد. و لقد اثبتت دقة الكميات المخمنة بواسطة ال(GIS) من خلال مقارنتها مع قيم الكميات المنفذة فعليا في موقع عمل مشروع بناء هندسة الخوارزمي، وحساب النسبة المئوية لدقة كميات ال(GIS) والتي بلغت 98.85% ، اضافة الى احتساب معامل الانحدار بين كميات ال(GIS) و الكميات المنفذة وقد بلغ هذا المعامل (R²) 0.999 وهو قريب من واحد و هذا يدل على ترابط كبير بين هذه القيم.

الكلمات الرئيسية: نظم المعلومات الجغرافية، جداول الكميات

1. Introduction

Progress in computerization and other automation techniques provides a great opportunity for improvement in construction materials management. Currently, the computer-aided design (CAD) system is widely used in engineering for drafting and design. As these CAD systems evolve, they are capable of generating materials requirements during the drawing phase and can be used to produce takeoff quantities. The benefit associated with this type of system is that a detailed takeoff of required quantities can be obtained directly from the CAD system, thereby eliminating the need to perform a detailed manual takeoff. However, because of the CAD system constraints of aggregating and distributing databases between locational and thematic attributes,
the containing information, such as materials types, quantities, location demands, and need dates, within the system cannot be automatically extended and reused in the construction phase for material planning purposes. The geographic information system (GIS), which combines a CAD-like design program with a relational database management system for spatial data analysis, appears to have potential in solving these problems. By replacing CAD with GIS, the bill of quantities (BOM) is generated based on the dimensions of the design drawings, thus incorporating a linkage of locational and thematic information.

2. Research Objectives

The main objective behind this paper was to develop an easy to use GIS based approach for quantity takeoffs in building construction. Other sub objectives that were to be achieved include accurate BOQ and development of construction resource database within GIS.

3.Gis In Construction Management

GIS is an appropriate technology to fulfill various requirements of the construction projects. It is capable of integrating diverse data sets, databases, and various applications. GIS improves collective decision making among planners, designers, and contractors [Mohamed, Jeffrey, Guy, and Alan, 1993].Therefore, reported works suggest that GIS is supporting the construction industry in several areas such as [Bansal, 2007]:
1. Subsurface Profile,
2. Quantity Takeoffs and Construction Cost Estimation,
3. Materials Layout at Construction Site,
4. Construction Site Layout,
5. Real -Time Schedule Monitoring System,
6. Route-Planning and,
7. Topography Visualization

3. 1. Subsurface Profile

[Camp and Brown,1993] suggested the use of GIS to develop a procedure for generating subsurface profiles from well-log data. The well-log database was constructed

from a series of borehole and GIS-base procedure was used to create 3D subsurface. [Oloufa and Papacostas, 1994] highlighted that site investigation is an important step in estimating and planning new construction projects and suggested the use GIS-based methodology to develop a database for foundations analysis, design and construction planning. As surface and subsurface conditions influence construction methods and choice of equipment, which in turn affect cost and scheduling of projects. Therefore, this study used database management capability of GIS to store descriptive soil data and to relate this data with the corresponding locations of boreholes.[Joshphar, Ganeswara, and Kok-Kwang, 2005] developed the national geotechnical information system (GeoInfoSys) for Singapore by integrating GIS with a relational database management system

(RDBMS) to develop a web-based geotechnical information system that can perform online spatial queries, generation of professional borelogs, and various geotechnical analysis. [Parsons, and Frost,2000] developed the GIS-ASSESS, which is a GIS-based tool designed to permit assessment of the adequacy, or thoroughness, of an investigation. GIS ASSESS was designed to be compatible with existing geostatistical software. It is capable of analyzing multidimensional data from multiple tools.

3.2. Quantity Takeoffs and Construction Cost Estimation

[Cheng and Yang,2001] suggested an approach for quantity takeoffs and cost estimation using Map/Info. Architectural drawing was divided into different layers, called data layers, for quantity takeoffs. In GIS-based cost estimates, area and perimeter were used as the basic parameters. Thus, data layers were created as polygons in AutoCAD and transferred to Map/Info in the form of geometric coverage. The geometric information of spatial features such as coordinate, area, perimeter and spatial relationship are derived from coverage.

Whereas, user enters thematic information such as identification (ID) code, beam number, floor number, etc. Recently, [Bansal and Pal, 2006] suggested the use of GIS for cost estimation in a more generalized way by adding new scripts into GIS environment for various cost estimation operations. ArcView, which utilizes the dynamic linkage between spatial and attribute data, was used for this purpose.

3. 3.Materials Layout at Construction Site

The MaterialPlan, a GIS-based tool developed by [Cheng and Yang, 2001] integrates quantity takeoffs with material layout planning. The system uses rules of thumb and experience to decide the size and location of material storage area. It assists planner in quantity takeoffs as well as in assessing material layout design. MaterialPlan developed by using a GIS environment integrate estimates with construction scheduling for dynamic materials requirement plan. Based on the information regarding quantities and locations of materials required in the project, the proposed methodology identifies the suitable site to store construction materials.

3.4. Construction Site Layout

The conventional approach to layout temporary facility (TFs) involves designing site layout using sketches, templates and 2D physical model. The developed layout is based upon the incomplete information stored in the different form. Such visual representations of TFs do not yield adequate and descriptive results. As TFs should be located close to their supporting activities to reduce the time for travel, the role of GIS may be explored for this. [Cheng and O'Connor, 1996] developed an automated site layout system called ArcSite using GIS for construction TFs. ArcSite consist of a GIS integrated with DBMS was claimed a new computerized tool to identify suitable area to locate TFs. ArcSite integrate information required to find suitable location for TFs and perform series of

complicated spatial operations and database queries to identify optimal site that is difficult to perform manually. ArcSite is a useful tool for construction site layout but the location of construction equipment as an important factor is not also considered in the system and the resulting layout of facilities may not arrive at the optimal solution. So that, [Sebt, Parvaresh, and Delavar, 2008] developed the system of GIS models which categorized into three parts; tower cranes, concrete batch plant, and temporary buildings.

3. 5. Real -Time Schedule Monitoring System

The commercially available scheduling tools such as: Primavera and Microsoft Project fail to provide information pertaining to spatial aspects of a construction project. Therefore Bansal integrated 3D model developed in AutoCAD and construction schedule developed in Microsoft Excel. Spatial and scheduling information are linked together into a GIS environment. Linking an activity with its schedule involves adding a field called key to schedule and its attribute table. The field key is common between two tables and used to establish the connection between the spatial aspect of activity and the corresponding activity in the schedule. All the entries in the field key are to be entered manually and should be unique in both schedule and attribute tables of an activity[Bansal,2007]. Furthermore instead of Microsoft Excel, Stephen and David were generating construction schedule by Primavera Project Planner (P3) then linked with Spatial information into GIS [Stephen and David, 2006]. Bansal and Pal used ArcView GIS for generating bar charts using its in-built chart document. Figure (1) shows the ArcView's chart document, utilized to show the schedule of the construction activities. The main advantage of the ArcView's chart document over conventional bar chart is that when a bar on bar chart in ArcView is clicked, a window appears which provide the information related to that particular activity [Bansaland Pal, 2006].

3.6. Route-Planning

Planning access routes for construction site is an important consideration in the development of an effective project-execution plan. The constructability and the maintainability of an industrial facility can be impaired if the access routes are not considered during project planning [Construction Management Committee of the ASCE Construction Division. 1991].

Hence Varghese, and O'Connor used GIS for selection a suitable route from many alternative by analyzing a number of scenarios via creating site geometry using AutoCAD environment and create geometry of vehicle turn envelopes then convert it to Arc/Info coverages, establish spatial relationships between roads, turns, and potential obstacles, and run graphical queries to gather additional information on road attributes and conduct analysis [Varghese, and O'Connor, 1995].

3. 7. Topography Visualization

GIS is an effective tool to visualize the topographical conditions of construction site. The modeling of construction site facilitates in construction controlling and planning process. GIS-based visual simulation system (GVSS) developed by Zhong and Song, is a tool that offers powerful planning, visualizing and querying capabilities as well as facilitate the detection of logical errors in a model [Zhong and Song, L., 2004].

4. Proposed Approach For Gis- Based Quantity Surveying

Automation quantity surveying by GIS is developed by using AutoCAD for producing spatial data (design drawings), and ArcGIS which have been used to extract, queried, manipulate, and analysis the quantity of different components of any construction project, from AutoCAD drawings, for reporting BOQ.

The proposed approach for automation BOQ by GIS can be categorized into:

1. Creating work breakdown structure
2. Creating AutoCAD drawings
3. Transferring AutoCAD drawings to ArcMap
4. Converting AutoCAD drawings to GIS format
5. Data integration
6. Creating database
7. Data manipulation and analysis.

The proposed approach for GIS- based quantity surveying implemented on the finished activities of the Al Khwarizmy College building as a construction project, according to design specification and the Iraqi United Standard Guide of Quantity Surveying for Building Works and Civil Engineering to compare the quantities estimated by GIS with the quantities that obtained from site surveying.

Al Khwarizmy project lies at Baghdad University at Al Jadyria section in Baghdad city. The area of the project is (5508 m²), the college consists of two floors with (92) rooms and other facilities for different purposes. The cost of the project is (ID 7.6 milliard).

4. 1. Creating Work Breakdown Structure

Work Breakdown Structure (WBS) illustrates the activities of the construction project according to the basic design of the project, to determine the data required for preparing BOQ, and to classify the layer of data for determining how many layers will represent the architectural design (AutoCAD drawings) that are required for preparing BOQ.

4. 2. Creating AutoCAD Drawings

AutoCAD drawings must be created to represent the data layer that required for any construction project. So, AutoCAD drawings have been created for the real life project that has been taken as a work field for this research are foundation, tie beams,

columns, beams, slaps, walls, stairs, parapets.

4. 3. Transferring AutoCAD Drawings to ArcMap

After creating drawings in AutoCAD, the dwg files were transferred to ArcMap a module of ArcGIS. The topologic data structure of the basic design layers in AutoCAD was created as layers in GIS based on the layers and activities identified in the AutoCAD drawings.

4. 4. Converting AutoCAD Drawings to GIS Format

The basic parameters required for quantity takeoffs are area, perimeter and depth. Thus, the topologic data structure of the basic design (AutoCAD drawings) layers are created as polygons or polyline via ArcMap and ArcCatalog (Figure 2).

4. 5. Data Integration

The geometric dimensions of the polygons or polyline in a single layer in some cases are insufficient for estimating the quantities of the activities, hence, join function of ArcMap is used to integrate layers. Thereby all the fields of the source attribute table are added to the destination table.

4. 6. Creating Database

In addition to the database that has been created with the editing process which includes objected, shape, length, and area. There is a need for creating a database via GIS analysis tools, such as: total area, codes, total volume, and etc.

4.7. Data Manipulation and Analysis

After extracting the required data from AutoCAD drawings by creating a feature class for each drawing, these data have been manipulated and analyzed to estimate the quantities and report BOQ.

5. The Comparison between The Quantities Of Gis, Boq And Site Surveying

After creating the bill of quantity by GIS by benefiting from the ability of GIS for creating reports, a comparison has been made between the quantities of GIS, BOQ and site surveying. This comparison show that The difference between the quantities that estimated by GIS and that obtained by site surveying is small as illustrated in Table (1) and the accuracy percentage of GIS (A%) that equals (98.85%) as illustrated below. While there are a big difference between tender quantities and quantities of site surveying in some items, and that causes to inaccurate the conventional estimation method. However, the difference between the quantities of GIS estimation and site surveying can be to many causes such as;

1. The difference between the accuracy of automated caused computer and human, especially when we know that there are more than one engineer has surveyed the quantities in the site and calculate the final values.
2. Depending on the payment of completed works on the quantity surveying for the finished activities in the site, hence the value of this quantity may be reduced if the contractor does not complete the activity according to the specification of the work.
3. Neglect the modification factor that must be run on the measurements of the surveying tools.
4. The difference between the drawing dimensions and the actual dimensions due to the variation orders in construction phase, or because to the difference between the accuracy of automated computer and human.
5. Do not following the specification of the Iraqi United Standard Guide of Quantity Surveying for Building Works and Civil Engineering in the site survey.

The validity of GIS for preparing BOQ has been proved by determining two values;
1. Accuracy percentage (A%) of the quantities that estimated by GIS that

was founded by the following equation equal to (98.85%):

$$A\% = 100\% - \frac{\left(\sum_{1}^{n}\frac{|Si-Gi|}{Si} \times 100\right)}{n} \quad (1)$$

Where:
A: The Accuracy Percentage.
Si: The Quantity of Each Item Obtained from the Site Surveying, so that;
Si = The Value of the fifth Column in Table (1).
Gi: The Quantity of Each Item Estimated by GIS, so that;
Gi = The Value of the sixth Column in Table (1).
n: The Total Number of Items, so that;
n = 14

2. The Regression Line (R^2) between the quantities of GIS and the quantities of site surveying.

$$R^2 = \left(\frac{\sum_{1}^{14}(Si-S)(Gi-G)}{\sqrt{\sum_{1}^{14}(Si-S)^2\sum_{1}^{14}(Gi-G)^2}}\right)^2 \quad (2)$$

Where:
R^2: The Regression Line.
Si: The Quantity of Each Item Obtained from the Site Surveying.
S: The Average of Si.
Gi: The Quantity of Each Item Estimated by GIS.
G: The Average of Gi.

So, R^2 = 0.999
The values A% and R^2 appears that the quantities estimated by GIS are very close to the quantities of site surveying, and there are big correlation between them. So that GIS has the validation for preparing BOQ.

6. Conclusions

The following points have been identified as the overall conclusion of the research:
1. The ability of GIS to integrate the graphical (AutoCAD drawing as related to this research) and attribute data in a single environment assist the project manager in handling the information in

properly and easy way with least cost due to the reduction of required staff, by eliminating the need for extracting data from various resources which also stored in different forms including graphics, text, tables, or various combinations of the three. Hence, the resulting benefits include faster estimating time, fewer take off errors, proper cost estimating, and better documentation for continuously reusing information in all construction phases.

2. Owing to GIS abilities of integrating the data which already stored as layers, the process of analysis and manipulation of the data is faster and more accurate than in the capabilities available. This lead to faster estimating time and accurate estimation.

3. The query mechanism of GIS allows different scenarios to be viewed (about dimensions, codes, location, …, and etc.) which will enable project manager to come up with positive solutions through manipulating and analyzing proper data, so in addition to accurate quantities estimation, the query mechanism will be helpful in monitoring the progress of activities and payment of completed works, also updating the database according to the variation orders in construction phase. Thereby, GIS involvement with the avoidance, management, and resolution of disputes in construction projects.

4. The ease of data distribution and access due to the ability of GIS to display the information with many methods such as displaying detailed design drawings have the quantities of related activities, enable the project managers to come up with positive solutions, and speed the estimating time.

5. The output or reporting functions of GIS (such as creating a BOQ) vary more in quality, accuracy and ease of use than in the capabilities available, which will assist managers in effectively organizing

and continuously reusing information for properly cost estimating and materials planning in construction phase.

7. Recomendations

1. The performance and utility of a GIS is dependent on the quality of data. Inadequate or incomplete information will dilute the extent to which a GIS application can achieve the required benefits. Hence data must be structured in a way which accords with the input requirements of the system.

2. Replacing the conventional approach for preparing BOQ with GIS.

3. Entering GIS techniques in engineering agencies for public and private sectors.

4. Integrating GIS concepts into civil engineering education not only to meet the urgent of non GIS professionals in engineering, but also to teach the students relevant skills in spatial analysis, reasoning and data processing.

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List Of Symbols

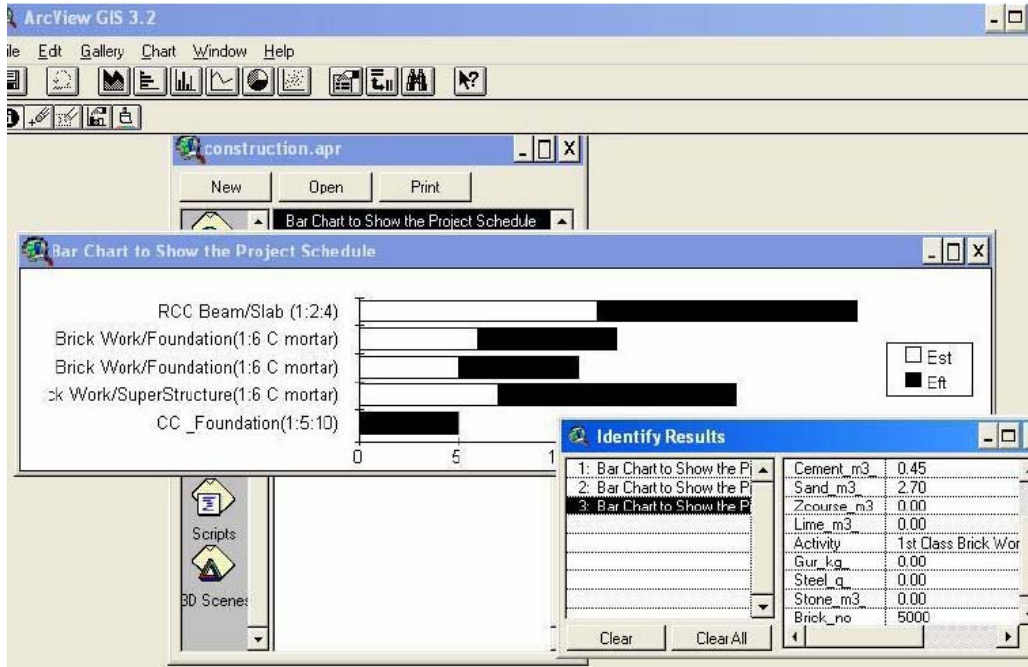|	
BOQ	Bills of Quantities
CAD	Computer-Aided Drafting
RDBMS	Relational Database Management System
GeoInfoSys	Geotechnical Information System
TFs	Temporary Facilities
DBMSs	Database Management Systems
3D	Three-Dimensional
GVSS	GIS-Based Visual Simulation System
P3	Primavera Project Planner
ID	Identification Descriptor
WBS	Work Break Structure

Fig. (1) Schedule of Activities in Arc View's Chart Document **[Bansal, and Pal, 2006]**.
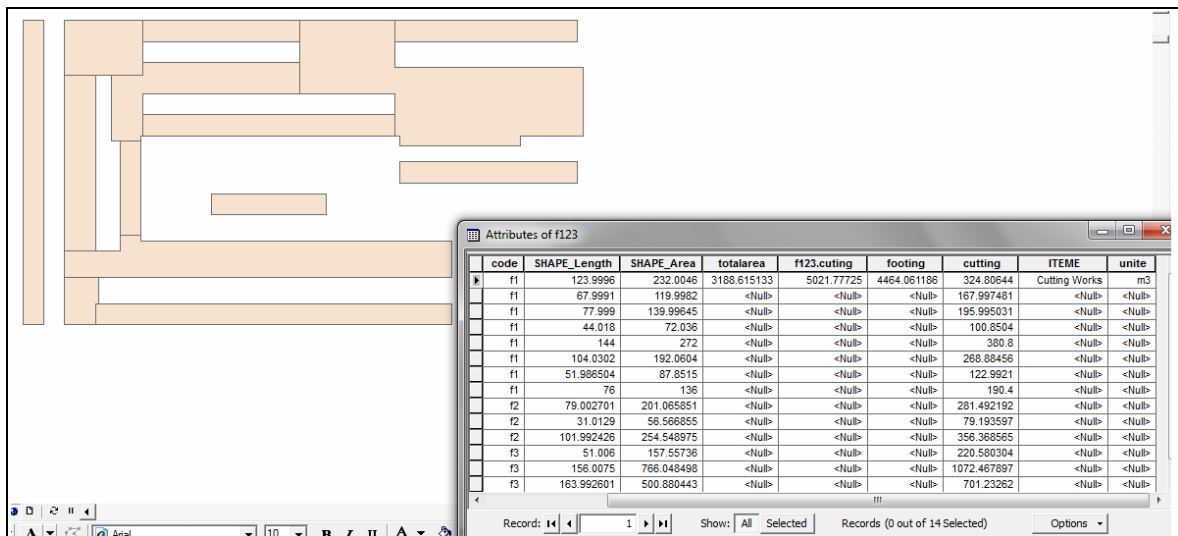

Fig. (2) Converting AutoCAD Drawings of Foundation to GIS Format

1

Table (1) Comparison the BOQ of Tender, Site, and GIS

	Item	Unit	BOQ (Tender)	Site	GIS
1	Excavations Works	m³	4000	5060.1	5021.78
2	Subbase	m³	3000	2188.93	2181.44
3	Chlorofet	m²	4000	4101.1	4102.23
4	Blinding	m²	4000	3528.44	3532.92
5	RC of Foundations	m³	2300	2550.8	2550.89
6	Rc of Pedestals	m³	100	89.7	89.23
7	RC of Interior Tie Beams	m³	110	170	167.43
8	RC of Exterior Tie Beams	m³	120	91.2	90.8
9	RC of Columns	m³	500	336.84	366.8
10	RC of Beams	m³	1400	1197.5	1203.34
11	RC of Parapets	m³	150	125.3	121.56
12	RC of Slab	m³	1000	1190.4	1182.47
13	Bricks	m³	_	110.69	115.12
14	RC of Stair	m³	_	11.2	11.081