Coordination Of Cost Estimation For Industrialized Residential Projects Through The Use Of BIM

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ABSTRACT

The current on-site (stick-built) construction process is hampered by inefficiencies and limited in terms of opportunities for technological innovation. The efficiency of on-site construction practice is contingent upon the effectiveness of the specific model used to communicate information. Architects use CAD models to develop a project design, while construction engineers use management tools and spreadsheets to assist in project estimating control and integration. Today, the efficiency of this process is dependent upon the ability of project participants to interpret these discipline-specific models in order to form mental pictures of a proposed design and manually perform material take-offs and estimating. This process contributes to misinterpretation and subsequent estimating errors. Advanced computer tools can be used to prepare smart designs which integrate these models and coordinate the cross-disciplinary tools used for design and cost estimating. The research described in this paper is intended to support the industrialized (manufactured) construction process of residential buildings, coordinating cross-disciplinary knowledge through the utilization of building information modelling (BIM)-based 3D-parematric modelling. A case study is also presented in this paper in order to illustrate the effectiveness of the methodology and highlight potential applications of the 3D BIM model.

Keywords -

BIM; Cost; Estimation; Automation; Coordination

1 Introduction

The current stick-built approach to residential construction remains encumbered by inefficiencies, rework, and lost time. In order to increase profitability, some homebuilders have shifted from conventional on-site building to off-site methods such as panelized construction. In this system, house panels are fabricated in a controlled environment and assembled on-site, ensuring better compliance with cost, schedule, and quality targets.

Despite considerable improvements in these respects, this system also imposes more strict deadlines, and requires efficient exchange of accurate data among departments, such as design and estimation data, since this construction approach entails that many projects will be progressing simultaneously and need to be effectively coordinated.

Moreover, the complex and active environment coupled with the asymmetry of data provided by different parties on a construction project leads to ambiguous information and conflicts (Schöttle and Gehbauer, 2012). An example of this problem is the poor interaction between architects and construction engineers, partly due to the lack of interoperability between tools used and deliverables produced.

As various parties involved in the project use different tools to perform their respective duties related to the project, they rely on their individual expertise to interpret and visualize drawings and manually generate take-offs for the purpose of estimation. This process contributes to misinterpretation and subsequent estimating errors.

According to Eastman et al. (2012), the use of 2D-based models at the design phase requires considerable time and expense to produce critical assessment information pertaining to the proposed design. For instance, using 2D models for cost estimation, analysis left to be done last when, in many cases, it is too late to implement important changes. In this context, the use of building information modelling (BIM) is highly recommended to address problems of interoperability and miscommunication.

BIM can be defined as a repository of information visualized in the form of 3D elements linked with a database that contains all the properties of the modelled elements, which facilitates collaboration and exchange of information among different stakeholders involved in a project (Miettinen and Paavola, 2014).

The most notable aspect of this fundamental shift toward BIM is that drawings are no longer just representations of a design; they carry information to be used by different parties along the process. Similar to with conventional representation (CAD), the details that the model carries vary, and as the level of detail increases, modelling consumes more time and effort. Therefore, it is important to not overload the model, and to define measuring standards to serve as a benchmark for defining the level of detail. In order to specify and classify the content of BIM models, the American Institute of Architects (AIA) has presented a 5-level scale called Level of Development (LOD) (BIM Protocol). Table 1, presented below, describes these levels, characteristics of elements, and authorized use for cost estimating.

Table 1. LOD levels adapted from AIA (2013)

LOD	Characteristics of elements	Cost estimation
100	Generic representation	Area, volume or similar
200	Approximate quantity, size, shape, location and orientation	Approximated geometries
300	Specific quantity, size, shape, location and orientation	Suitable for procurement based on specific data
400	300 LOD and detailing, fabrication, assembly and installation information	Based on actual cost of the element model
500	Verified model on filed	Not applicable

The specifications presented by AIA categorize the level of detail provided by the virtual prototype through project phases and decisions being performed. Despite the high level of detail that can be provided, a BIM model may not need to attain LOD 500 in order to fulfil its objectives, depending on the scope determined. Therefore, if a lower LOD is acceptable within the defined scope, this entails that less time and effort is expended to provide the information needed, leading to cost savings in the design phase.

Estimating is "*a quantitative assessment of the likely amount or outcome*" (PMBOK 2011). Project cost estimating is a key factor in the construction industry since it connects cost with other factors that influence the project total cost, such as time, productivity and available resources, during the project's life cycle. Estimate depends highly on project's maturity level of information (design drawings and specifications); consequently, project phases, estimation techniques and estimation's accuracy are intensively connected. The Association for the Advancement of Cost Engineering (AACE) International classifies estimates, according to "*the maturity level of project definition deliverable*" (AACE 2011, 2), into five classes, as presented on Table 2. Class 5 is related to the lowest maturity level of information, while Class 1 is created with the highest maturity level of project information (AACE 2011, Boeschoten 2003).

Table 2. Estimate classes According to AACE

Estimate Class	Maturity Level of Project Definition (%) and final purpose of estimate
Class 5	0 to 2 Screening or feasibility
Class 4	1 to 15 Concept study of feasibility
Class 3	10 to 40 Budget authorization or control
Class 2	30 to 75 Control or bid/tender
Class 1	65 to 100 Check estimate or bid/tender

The research presented in this paper seeks to evaluate improvements brought by the use of BIM applications in the estimation department of a construction company in Alberta, Canada, and analyzes the workflow between different departments involved in the process.

As demonstrated in the case study, automated quantity take-offs reduce significantly the time spent on estimation. Using BIM also increases coordination and collaboration between the involved parties and minimizes clashes. Therefore, a parametric estimation linked to a BIM model has the potential to reduce change orders and uncertainties throughout the project due to its interoperability between the modelled elements. This can be translated to the calculation of contingencies and reduction of claims, thereby reducing the overall risk associated with the project. Eastman et al. (2011) have stated that a detailed building model can be utilized as a risk mitigation tool; also, Reddy (2012) have suggested that BIM can be "*effectively utilized by parties to assume more risk while reducing contingency*". Moreover, other research studies have found that the application of BIM and Integrated Project Delivery (IPD) can reduce change orders by 32% and requests for information by 74% compared with traditionally delivered projects (Liu 2013). However, the use of BIM remains undermined by several factors such as the lack of methodologies addressing BIM in the estimation process and the resistance to change in a company's work flow.

This project suggests a methodology that relates parametric 3D elements with various types of information such as construction phases and unit rates through codes used in accounting, production and estimating. Formulas are introduced for respective elements in order to extract the correct take-off of each item in the estimation and calculate its total cost.

The second challenge, perhaps the most formidable facing BIM practitioners, is the resistance and confusion within industry with respect to the shift toward BIM

2 Research Methodology

This research is implemented at a construction company in Alberta, Canada that builds 1,000 homes per year. Given their high production volume, any improvement of the planning phase can bring significant savings.

The methodology is carried out in three main parts. First, a study of the current workflow is performed in order to identify potential areas of improvement. Second, modelling procedures are adapted in order to link the modelled elements of the design with accounting codes used in the company; the LOD of the model is minimized in order to reduce the amount of work required of the drafting department. Finally, estimation items are linked with element geometries, and purchase order reports are created that match those currently issued by the company.

2.1 Current workflow

The company has 25 different house models (from single-family detached to duplex and townhome), and also allows the client to customize their unit according to their needs. In order to update and improve the design and drafting process to accommodate the many design options it offers, the company has already shifted its modelling tools from CAD to BIM.

However, it is observed that, even with the use of automated take-offs that can be extracted from design models, the estimation department is still relying on manual quantification from PDF drawings. According to interviews with company personnel, this is due to the lack of compatibility between the information provided by the model and the data required by estimators.

Figure 1 demonstrates the workflow for a typical project in the estimating department. According to Figure 1, the estimator receives and revises all drawings and specifications related to the new project. Next, the estimator performs the take-offs for the project and issues purchase orders to different trades in order to start the job. The last stage involves controlling the cost initially budgeted for the project and correcting any errors that may have occurred during the planning phase, as the estimator receives progress reports from site superintendents and bills from contractors and issues purchase orders so they can track the cost.

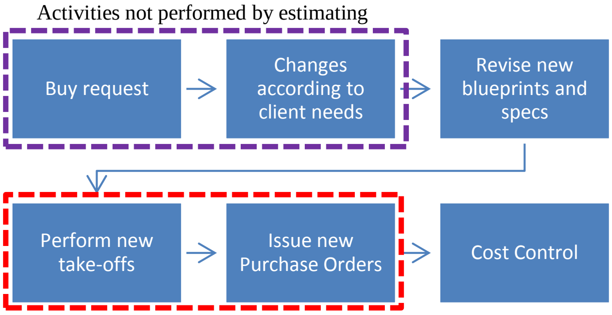

Figure 1. Company current workflow

The take-off and purchase order processes are identified as opportunities to improve the company workflow, since these steps are the most prone to error, and since these two tasks combined account for 40% of the time expended by estimators on a given project.

2.2 Modelling procedures for parametric estimation

Vico software is selected as the tool to manage the BIM model and perform parametric estimation. Using Vico Software, the take-off can be derived from formulas dependent on BIM elements. Since estimation items depend primarily on element geometry, element naming in the BIM model becomes an important step in connecting this model with any documentation outside the design scope.

Another challenge is to keep the parametric model as simple as possible in order to avoid unnecessary effort in extra-detailing from drafters and designers.

The BIM models provided by the company present a large number of element types and a variety of sizes, materials, and specifications. A generic naming convention for all items in the model is created so formulas can be used in any project regardless of its specifications or typology. For an example of the developed naming convention, we consider pile caps (for the foundation): instead of naming the element by size (e.g., “40 x 40”), it is named “FP 1” (“F” stands for “foundation” and “P” stands for “pile”), so the formula is not affected by a change in the element’s size. The element geometry changes as its size changes, but the formula (e.g., FP 1.Volume) is not modified, ensuring a correct take-off.

The LOD of the provided models is reduced from 400 to 300 in order to perform its estimations through formulas in Vico Software derived from the geometry of the elements. This brings a considerable reduction in drafting time, as the number of element types in the model is reduced.

2.3 Model linkage and creation of parametric reports

Vico software provides built-in take-offs (or “TOQ”, as they are called in the Vico software) for each element (or “TOI”, as they are called in the Vico software), thus facilitating the take-off process. Figure 2 shows the roadmap of BIM implementation for the estimation department. Importing the adapted BIM model and data related to estimation in the initial format of spreadsheets into Vico environment, items and unit rates are connected with 3D elements in order to perform the cost estimation. With the cost estimation complete, cost reports such as purchase orders can be created and directed to different stakeholders.

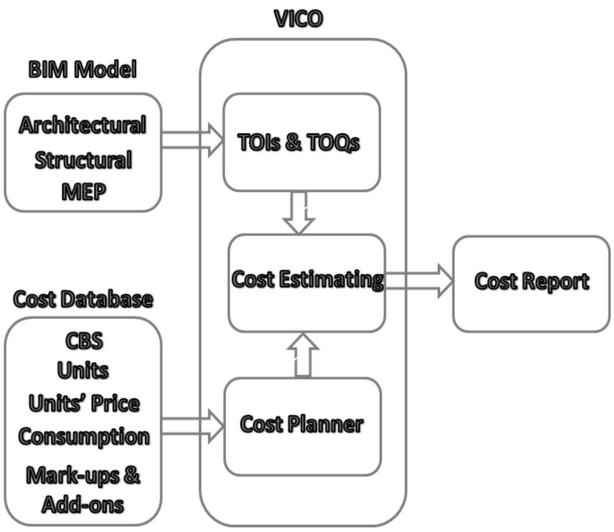

Figure 2. Roadmap of BIM implementation

3 Case Study

The project selected for the implementation of this methodology is a single-family unit with basement, two floors, attached garage, and an area of 2,386 ft^2. The aim of the research is to reorganize and use existing information provided by the drafting department in order to enhance the performance of the estimation department.

The study is implemented in two phases. The first involves adapting the modelling procedure under the required specifications, focusing on architectural designs and identifying representative items without a unit price for later investigation. The second phase encompasses the integration of MEP designs into the parametric estimation process and the acquisition of unit rates from representative lump sum contracts provided by trades.

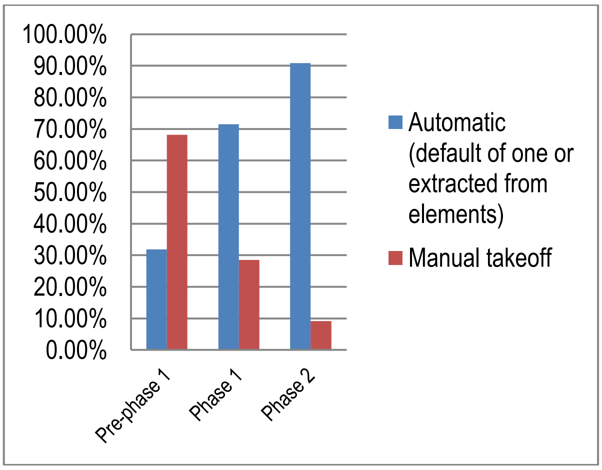

Figure 3. Quantity take-off procedures through project phases

Figure 3 presents a comparison between the existing situation (pre-phase 1) and the subsequent phases of this study. Initially approximately 30% of the estimated items are a default quantity of one (e.g., land, building permits), as the remaining items must be quantified by estimators on every project according to changes proposed by clients or particularities from the given project. In the first phase an automation level of more than 70% is achieved for the take-off process, associating default unitary take-off formulae taken from BIM model element geometrics and estimation items with their respective unitary costs.

With the integration of MEP systems in the BIM model and breakdown of representative items from a lump sum cost to a unit rate, a level of automation of almost 90% of estimation items is achieved. This constitutes a more reliable process, diminishing the likelihood of errors and rework as a result of multi-party collaboration or design changes during the project. As previously investigated, the quantity take-off process represents roughly 40% of the time required to estimate a similar project; this methodology presents an estimated 30% reduction in the estimation process per project.

Additionally, custom reports are created in order to assist the estimator and provide information to different stakeholders. The most common report used is the purchase orders to be sent to trades. Figure 4 shows a comparison between the purchase order template currently utilized (on the left) and the one extracted directly from the parametric estimation (on the right). As Figure 4 demonstrates, although the two are similar, the one issued by the parametric model ensures that quantity and unit prices are correctly placed.

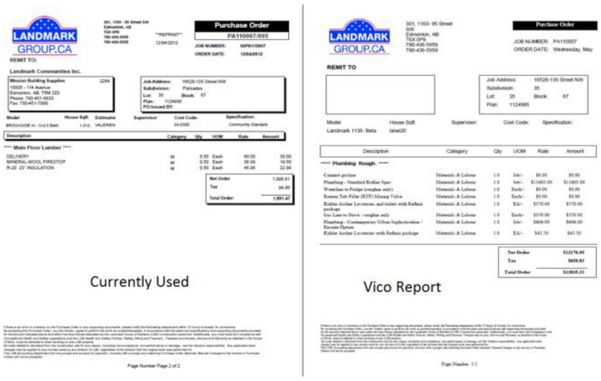

Figure 4: Comparison of proposed and existing purchase order forms

3.1 Data Classification

Data acquiring techniques in the company could be classified into (4) categories:

- Automatic-by-default, this type of data should be entered once in the cost model, and then it is maintained when certain requirements differ according to the project. Land's value is an example for this type.
- Automatic extraction from the elements, significant portion of data is goes under this category; this type of data is related to the properties of the building's elements, such as the volume of concrete in the structural slab, or the number of studs in a given wall.
- Manual-entry data, this is for data that are special for certain project and special circumstances.
- Data with extra information needed. This type of data has the potential to be completely extracted automatically. However, because of the lack of information this fully-automation is not achievable.

Figure (5) shows the distribution of those categories in the company.

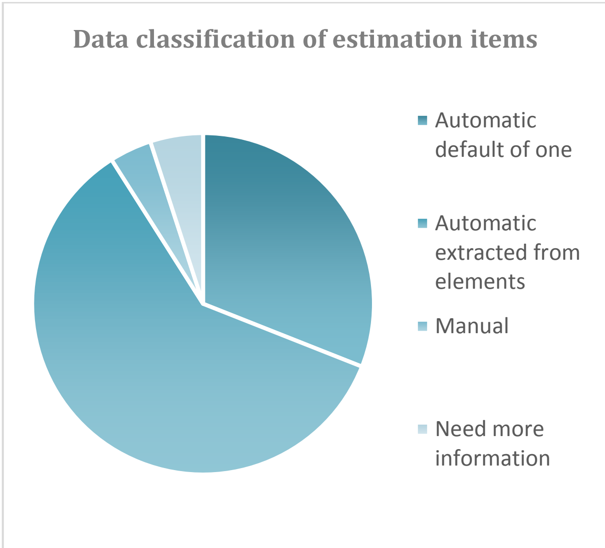

Figure 5. Distribution of data in the company into the different categories.

3.2 Challenges

The lack of information provided was the main challenge this project had. The accuracy of result depends on the level of detail about the cost item available to match. Any insufficient data would hinder the use of unit-bases estimation, and consider the cost as lump-sum. MEP items are examples for this case. Where modelling MEP item is affordable in terms of time and effort needed, contractors tend not to provide information pertaining to their pricing techniques. Yet, they provide their prices as lump-sum. With the absence of certain pattern of pricing, the team chose prices per area unit to compromise the lack of more precise method of estimating the potential cost. Moreover, the team encountered resistance to the proposed changes from some employees due to lack of familiarity with BIM tools or confusion about the use of specific software programs and the benefits of parametric modelling for estimation. When dealing with BIM, drafters must be taught that the BIM model contains information beyond the mere visual representation associated with 2D drawings, and that their work encompasses modelling data to be directly used by different parties (in place of the lines and dots previously computed by CAD platforms.)

4 Conclusion

BIM tools have been widely used to speed and improve the design and take-off process in construction, but little has been documented regarding its use for cost estimation. This paper has presented a methodology to organize BIM models from an estimation perspective without compromising any aspect of the design phase. Based on a detailed study of the current workflow of a homebuilder employing a panelized construction approach, the research team identified gaps and possible areas of improvement and was able to track and quantify these prospective enhancements.

The set of procedures identified allows drafters to produce their models at LOD 300 or lower and still extract detailed information equivalent to an LOD 400 model with the assistance of Vico Software.

Regarding enhancements in the company's estimation department, the study developed measures to reduce the estimating process by 30% while still generating accurate take-off and documentation. The proposed model is also capable of providing the same deliverables issued currently, ensuring effective information workflow throughout the entire process.

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