Technology Ontology and BIM-enabled Estimating for Owners and Contractors

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ABSTRACT

A database of construction methods can help select the optimal approach to building a construction project. To be useful, such a database should be integrated with BIM, and thus, be based on a consistent methodology to define and classify construction methods. Contractors' are confronted with problems in selecting proper construction methods and applying their knowledge about specific and well-defined technologies to a project. This paper proves empirically that selecting the right methods using one of the technologies available for multiple activities would create accurate costs when not only materials are priced, but also right equipment and available labor. This way, owners can efficiently demand deliverables that can be utilized by them downstream, allowing Contractors and subcontracting trades to work efficiently and to assure the daily flow of operations.

Keywords: Owner, Contractor, BIM, ontology, estimating, construction technology

INTRODUCTION AND LITERATURE REVIEW

The Architect's Handbook of Professional Practice defines detailed cost estimating as “a forecast of construction cost prepared on the basis of a detailed analysis of materials and labor for all items of work” (Dell'Isola, 2003). Owners “expect that an accurately defined budget will be prepared early in a project and that the project will be completed to required scope, meeting expectations of quality and performance, all within budget” (Dell'Isola, 2003). To ensure that the project is within budget, some owners will require a detailed estimate early in the design phase, before construction begins. Detailed cost estimating require a good amount of time, precision, attention to detail, consistency in methods of preparation, and knowledge of constructability. Knowledge of construction processes is very “useful, especially for processes and sequences not typically drawn and detailed in construction documents, such as excavation, form work, sheeting and shoring, false work, and a variety of general conditions” (Dell'Isola, 2003).

BIM models can provide accurate, automated quantification and a thorough understanding of the building system as a whole. The model “helps architects, engineers and constructors to visualize what is to be built in simulated environment and to identify potential design, construction or operational problems" (Azhar et.al, 2008). BIM models are a "data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and to improve the process of delivering the facility" (Azhar et.al, 2008).

Accuracy depends on how well developed the objects and assemblies are in the model. The method of cost calculations in the different design phases will vary because "earlier phases will use a more generalized cost per linear foot" and later on in the final design, estimators will derive a total area for each building material (Sabol, 2008). BIM models can also provide feedback to the project team at all phases of the design and construction. This is helpful when developing preliminary cost estimates for the owner because the estimator can provide feedback on the design's constructability and offer cost saving solutions. Through the use of the BIM "costing exercises throughout the project" it offers the "promise of reducing the need for value engineering by supporting the decision-making process with more accurate information, earlier in the project" (Sabol, 2008). Owners will be offered better-cost savings through reduced errors in quantity take-offs (QTO) as well as offering more cost efficient alternative materials and methods. Architects will be able to keep up with their design costs and insure it is staying within the budget without spending an intensive amount of time quantifying their project. The tool developed by Cheung et.al. (2012) allows users to evaluate the functionality, economics and performance of buildings concurrently with building design. To illustrate the mechanics of the tool, their paper details the cost estimation module that enables quick and intuitive exploration of early stage design in a popular 3D modeling environment. Measurements are automatically extracted from 3D models and profile driven estimates are revised in real-time. However, the level of confidence in the estimates performed at early stages is still low. Research on 32 major projects conducted by Stanford University Center for Integrated Facilities Engineering (CIFE) showed that effective cost estimation software combined with BIM, can eliminate 50% of unbudgeted change, narrow the cost estimation accuracy to within 3%, reduce the time taken to generate a cost estimate by about 80%, save of up to 10% of the contract value through clash detections, and reduce project time by 7% (Azhar et.al, 2008). According to Autodesk (Revit BIM, 2007), about "50-80% of the time needed to create a cost estimate is spent just on quantification". The use of BIM provides a more thorough understanding of the design, cost estimation and scheduling and saves money and time as well.

OBJECTIVE OF THE TECHNOLOGY ONTOLOGY

A consistent methodology to unequivocally define and classify construction methods was presented in an earlier publication by Maghiar and Wiezel (2013). Called a technology taxonomy, the classification it is attaching the concept of technology to the existing construction estimating processes. The expectation for the technology taxonomy is to improve the decision-making process at the management level by opening the possibility to implement construction methods into a BIM and thus enabling early semi-automatic detailed estimates that take into account the construction methods envisioned by the project management team. To prepare reliable estimates, the estimate methodology must be commensurate with the desired level of accuracy and the level of scope definition at the time the estimate is prepared. The accuracy of any estimate depends on the quantity and quality of information known about the project. Simply put, a more precise definition yields a more accurate estimate. When scope is not clearly defined, the experience and skills of the team, and the estimators in particular have a significant impact on estimate accuracy. This research is proving that a domain of estimate optimization exists. Moreover, the technology ontology domain applied to an estimating process can have a significant impact on the accuracy of the estimate for Owners and Contractors. Niknam and Karshenas (2013) discuss how ontologies can be used to publish product information and develop ontology-based estimating applications. Xu, et. al. (2013) introduced a new philosophic stance for cost estimation to address the development of model based cost estimation addressing the importance of contextual information and the needs of extension of pricing information according to the general process of cost estimation by using the IFC standard.

A number of estimates are performed throughout the life of a project. These include feasibility estimates, conceptual estimates, contractor's bid estimates, progress estimates and so on. Although these types of estimates are generally known by these terms, they can vary slightly from case to case and from company to company. Furthermore, there are no clearly defined boundaries between each type. Figure 1 presents the major types of estimates and their expected level of accuracies, based on the life time cycle of the project. The hatched areas between the curves represented in the figure are boundaries of the least accurate estimates and the most accurate estimates relative to the life time cycle of the project for a given estimating strategy.

The scope of this study is to narrow down the domain between the two curves (to narrow the range of the hatched areas) and to lower the range all-together, to achieve a better level of expected accuracy Figure 1 shows the general progression from the least to the most accurate estimating types. Better expected accuracy can be achieved through cost analyses and alternative construction methods or alternative materials. This process can reduce the cost and duration of the project. Therefore, time and money can be saved. Speaking in more generalized terms, a construction method is considered a function generated by resources (materials-M, labor-L, equipment-E) and techniques (see equation 1).

$$\text{Construction Method} = f\left[\underbrace{resources}_{\swarrow\ \downarrow\ \searrow \atop M\quad L\quad E}, techniques\right] \qquad (1)$$

The estimator's job is to fully consider the products and the processes in the building process and attach a cost to them with as much accuracy as possible during the lifetime of the project.

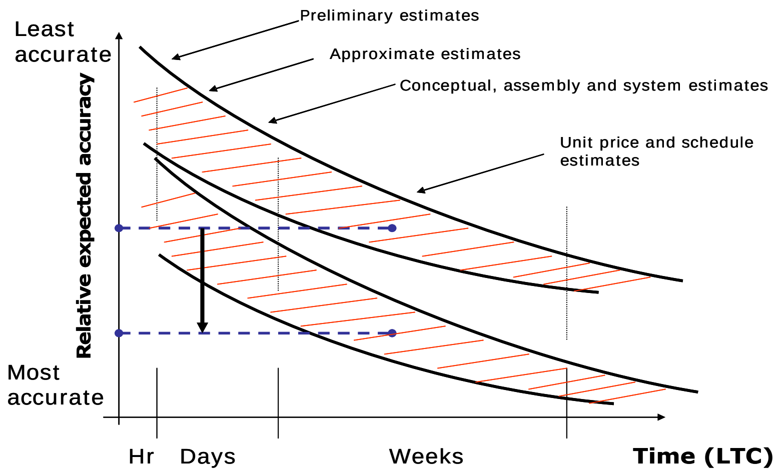


Figure 1. Relative expected accuracy in the selection of the method process

Ontology development – technologies. Activities can be defined as the processes through which the chemistry, shape or location of a product is changed. Activities can be performed using various methods, and each method may be implemented by using different techniques. For example, a cast in place concrete column needs to have forms in place. The forms can be made of plywood, steel, aluminum, plastic, and so on. There are different techniques of how to use and attach this formwork (Table 1).

Table 1. Methods and techniques for construction of column activity

Assembly	Activity	Method	Technique
		Plywood	w/ tie wire, one use
Columns	Forms	Plywood	w/ tie wire, four uses
		Steel	Panels and rapid clamps
		Aluminum	Post and beam

In the process of estimating, all resources are quantified and receive a price per unit. By definition, activity consumption is the amount of resources needed to produce one unit of an activity. So, when selecting methods and techniques to be used for an operation (making an assembly), materials, equipment, and labor are quantified and, before receiving a price, *a consumption* is assigned to each resource. The technology used to build the respective assembly is a combination of ancillaries, end-effectors, and equipment used to produce the assembly. For visualization, a flow chart is shown in figure 2.

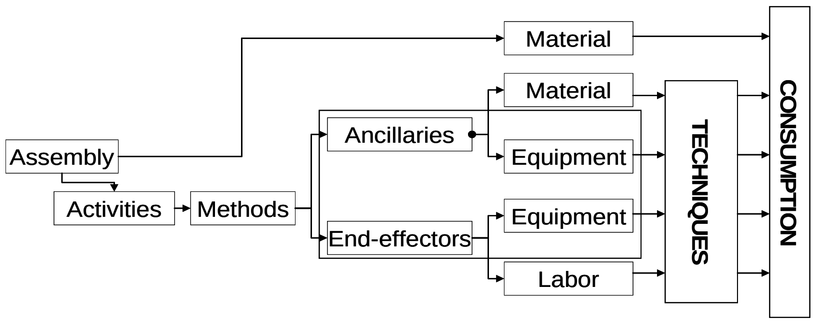


Figure 2. Assemblies and technologies in estimating

A method descriptor will have ancillaries, equipment (including tools), and end-effectors. For instance, in an activity description of "Backfill, Structural Dozer or F.E. loader, 300' haul, sand and gravel, 75 HP Dozer", the method descriptor is 75 HP dozer. Using a 105 HP dozer would represent, in this case, a different method. Other examples of method descriptors are "plywood forms (four uses)", or "power saws", or "hydraulic cranes, 55 tons capacity".

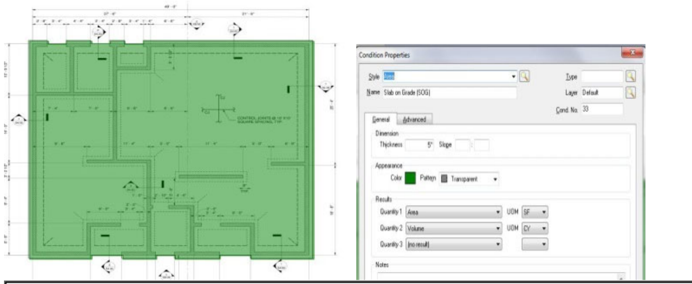
METHODOLOGY – A BIM CASE STUDY

Reducing the time an estimator takes to manually quantify the project, their time and expertise can be shifted towards providing a higher quality estimate, identifying construction methods and assemblies, and factoring risks. The benefits of using BIM models for cost estimation are illustrated through a construction project of a Stadium expansion that was aggregated into a virtual Autodesk Revit model and derived quantities from the building materials. By having access to the projects BIM model, preparing an estimate is not only faster, but more accurate, as presented in this paper. For comparison, the study utilized a general contractor's estimate for the Stadium Expansion and compared the derived estimate to traditional methods. The quantities were extracted from the model that has been created and compare it to the general contractor's estimate that was created from on screen take-off (OST) quantifications. Through this project, the comparison of the QTO obtained from the Revit model and OST showed the ease of obtaining a more accurate QTO.

This section presents the findings of the study of performing the quantity take-off in Autodesk Revit and OST. There were three buildings modeled: two restroom buildings and the concession/novelty store building, all part of the Stadium Expansion Project. The buildings were modeled with the intention of extracting quantities. The quantity estimate is only as good as the model created, hence the skill of the BIM modeler is essential. Since the design team usually provides the model, an experienced estimator with BIM experience should review it because a quantity takeoff is not a basic function.

To compare the accuracy of OST method vs. BIM, quantities have been derived for the following: Slab on grade, Flooring, Ceiling and Doors.

Slab on Grade QTO Methods. First a quantity is derived for the slab on grade foundation for the three buildings. The unit for slab on grade is area and volume of the concrete material. To find the quantity in OST, the estimator must trace the perimeter of the slab, as shown in Figure 3 below. Quantities given once the perimeter is marked can be the area and volume. To calculate the volume, the estimator must include the height of the slab, as shown in Figure 3. Common mistakes in finding the volume are that it is calculated in CF instead of CY or the height is not entered correctly. In Revit, the estimator must ensure that the object drawn is inclusive of all desired areas.



Floor Material Takeoff

Family and Type	Area	Assembly Description	Family	Material: Volume	Volume
Floor: 5" Concrete	2000 SF	Floor Construction	Floor	833.27 CF	30.86 CY
Floor: 5" Concrete	3618 SF	Floor Construction	Floor	1507.43 CF	55.83 CY
Floor: 5" Concrete	1986 SF	Floor Construction	Floor	827.54 CF	30.65 CY
Floor: 5" Concrete: 3					
Floor: Carpet Tile	1031 SF	Floor Construction	Floor	10.74 CF	0.40 CY
Floor: Carpet Tile: 1					

Figure 3. Slab on Grade and Condition Properties (OST)

Flooring QTO Methods. Additional information can be derived from the floor material take-off in Revit. Since the buildings in the case study had two types of flooring (carpet and sealed concrete), the flooring quantity can be taken from the same schedule as the slab on grade. To calculate the quantity for sealed concrete, one must take the area of the 5”concrete slab and subtract the area of the carpet. The carpet area is automatically calculated. Common mistakes when calculating the quantity for carpet are to ensure the correct unit. Some estimators calculate the area in different units (i.e. square foot and square yard).

To calculate the area in OST, the perimeter of the rooms of each type of flooring needs to be traced. Multiple units can be calculated from the condition properties as shown in Figure 4.

Ceiling QTO Methods. Similar to flooring, the ceiling is a simple take-off. For OST, the estimator must trace around the room for each type of ceiling The unit for ceiling types is SF. In OST, that each type is taken off separately, while in Revit, simply schedule is created ceiling is selected. For this project, there were only 3 types of ceilings: ACT-1, ACT-2, Stainless Steel Panels, and all other areas were open to structure.

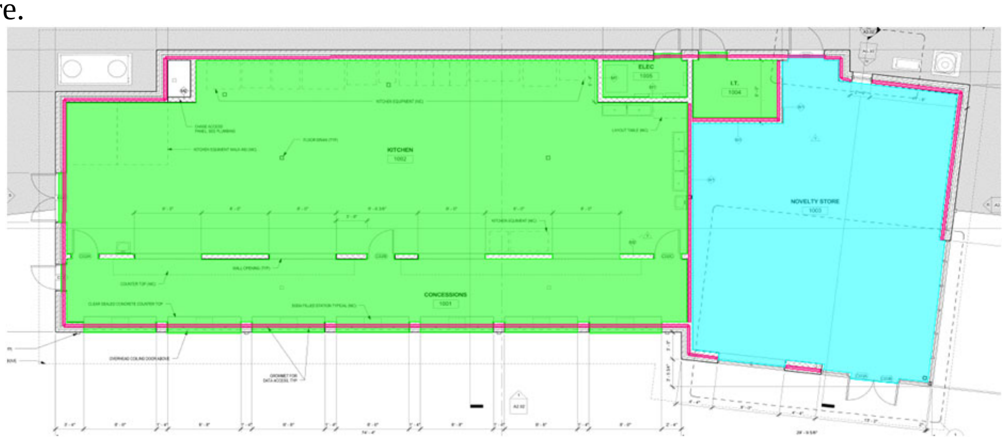


Figure 4. OST Flooring Take-off

As indicated in the Table 2, the OST take-off numbers were comparable to the quantities derived from the model. There was a 5.5% increase in quantity from the OST take-off to the quantity from the model. This 5.5% can possibly add up to be a costly mistake when competitively bidding on a project, which is why it is important to accurately estimate a job. By having different methods of estimating, it also insures that the estimator is getting a more accurate quantity.

Table 2: OST Ceiling Material Take-off and Revit Ceiling Material Take-off

Ceiling Schedule			
Family and Type	Assembly Na	Assembly De	Area
Basic Ceiling: ACT- 2		Ceiling Finish	1592 SF
Basic Ceiling: ACT-1		Ceiling Finish	1006 SF
Compound Ceiling: GWB on Mtl Stud		Suspended	29 SF
Basic Ceiling: SS Panel		Ceiling Finish	45 SF

CONCLUSIONS AND DISCUSSION

When comparing the two procedures, the time on task was a lot less using the model to extract quantities and the accuracy of the quote was more precise. In the study conducted by Alder, “those using the BIM method had, on average, a percentage of error of 1% for this takeoff, whereas on-screen takeoff users had a 3% error” (Alder, 2006). To draw a better conclusion from this study, more tests need to be conducted to determine the accuracy on the two procedures. The study is limited to only the study of certain building elements defined. Other limitations of the study would be the level of details in Revit for the parametric objects created in the initial model. Utilization of the program provides many benefits to the entire project team (i.e. clients/owners, designers, contractors, subcontractors). Further research should be conducted to compare estimates generated by the two procedures: OST from construction plans and detailed models generated from CAD files and structural plans. A more complete study would include takeoff performed by an experienced professional estimator, a BIM model created by a professional designer, and an experienced estimator that is familiar with the BIM quantity take-off tools. Also, technologies available in a company setting would add value to the study because methods selection used in estimating process would illustrate a certain difference in obtaining estimate accuracy. The totality of these technologies, and the resource allocation, make up the domain for estimate optimization. Selecting the right methods based on method descriptors, using one of the technologies available for multiple activities would create accurate costs when not only materials are prices, but also right equipment and available labor. Through method selection, technologies for the site assemblies are selected. As a counterexample, for backfill and/or excavation activity, the estimator can choose to bring three different types of equipment to the site. A further consideration related to quality optimization of the work or safety procedures for construction people in the site makes the actual scope or purpose of the optimization. Depending on the scope of optimization they can use: backhoe loader – 48 HP, dozer – 105 HP or dozer – 75 HP (as an example).

RECOMMENDATIONS FOR FURTHER STUDIES

Graphical representation in figure 1 is an attempt to create a better description of the concept map of estimates, so the first recommendation for further research is to acquire a more precise representation through more case studies. The present representation is comprised on the approach that there is an influence of using various construction methods reflected in the expected relative accuracy of estimating. The existing relationships between the items or assemblies generated in a new estimate from BIM and a specific technology built within the estimate, and recalled from various databases of the estimate, is beyond the scope of this research. Once details of relationships are known, construction methods and available technologies can be automatically aggregated and computationally integrated into activities, therefore the whole construction process can be optimized for time, cost, quality, or safety. Another recommendation for further research is the actual domain of estimate optimization. The optimization of the estimate, based on the technology ontology, was not the purpose of this study. However, a series of new research studies, pertaining to the scope of optimization, can be undertaken for further development.

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