to 18 in., the cost of which includes leveling (strike off) and consolidation, but excludes material.

- Flat slab with drop panels of roof is formed by cast-in-place concrete forms made of 2-use plywood. The form is shored, erected and braced; after the concrete is poured and cured, the formwork is stripped and cleaned. Curb forms of the roof, which is 6 in. to 12 in. high, are formed by cast-in-place concrete with forms made of 1-use plywood. The form is shored, erected and braced; after the concrete is poured and cured, the formwork is stripped and cleaned; structural concrete, which is 6 in. to 10 in. thick, is placed via crane and bucket, the cost of which includes leveling (strike off) and consolidation, but excludes material.
- Concrete block for masonry is of high strength, hollow, 5,000 psi, 12 in. × 8 in. × 16 in. Mortar and horizontal joint reinforcing for every other block will be applied; scaffolding, grout and vertical reinforcing will be included in construction.
- Residential garage metal door (incl. hardware, excl. frame) with rubber weather stripping is installed for this project.
- Window costs including frames, screens and grilles need to be considered.

The following figure shows two examples of lower level WBS.

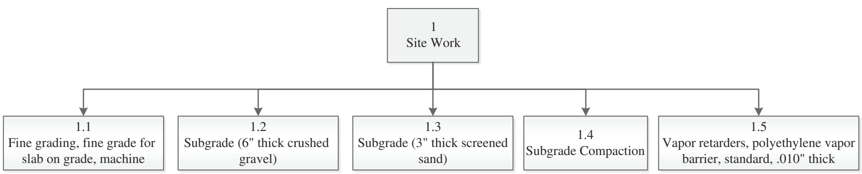

Figure 5-34. Examples of lower level (example 1)

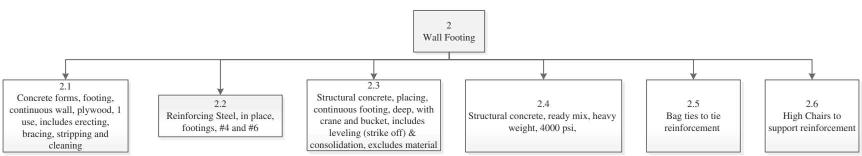

Figure 5-35. WBS examples of lower level (example 2)

3. Search RSMeans Items

Identify "Line number" and "Crew ID" for each work item defined in the lower level WBS based on Master Format 2010 (searching RS Means On-Line.com), and **complete** the following table.

Hints:

You can search for the required items using the item's **Description** or the item's **Line Number**.

Searching by item's Description allows you to enter keywords such as "fine grading" (Fig. 5-36).

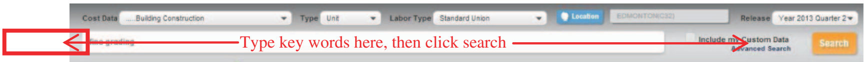

Figure 5-36. Search by item's description

Searching by item's Line Number allows you to type in a partial or full 12-digit CSI Line Number (Fig. 5-37).

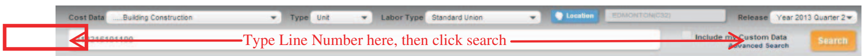

Figure 5-37. Search by line number

You can also use "**The Search Tree**"

The Search Tree is located on the left margin of the Estimate View and Cost Books windows (Fig. 5-38).

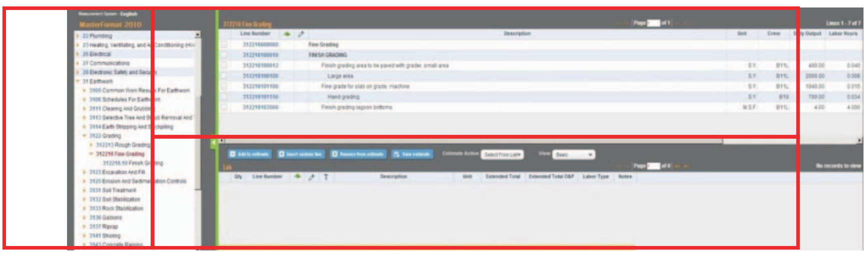

Figure 5-38. Search by search tree

The Search Tree is used for locating particular cost lines.

– Once you have located the desired cost line within the Cost Book, select the individual Cost Data line by clicking in the box located on the left of the Cost Data line, as shown below (Fig. 5-39).

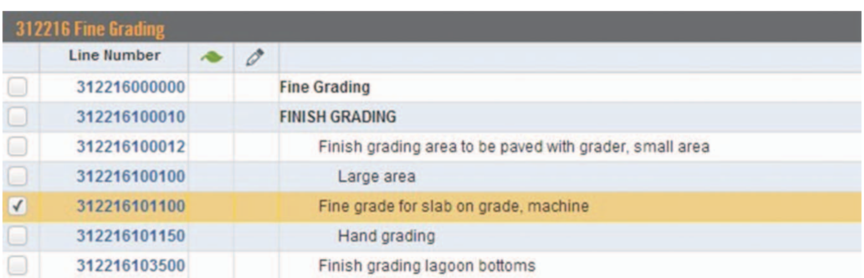

Figure 5-39. Add to the current estimate

– Clicking the Add button located between the Cost Data Book window and the Current Estimate window will add this line to the Current Estimate. Once this line appears in the Current Estimate area, you will be prompted to enter a quantity for this item. Note this quantity is the outcome of takeoff process based on 3D/2D information given in the validated Revit model. Table 5-4 template demonstrates how each team organizes and presents findings for this part of the project report.

Table 5-4. WBS Established Based on MasterFormat—Template

Upper WBS	Lower WBS	Line Number	Crew ID	Units	Description
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–

By referencing RS Means on-line.com, elaborate what laborers, equipment and tools (Crew ID in Table 5-4) the contractor needs to employ on this project. Summarize relevant crew information using a table design (as per Table 5-5).

Table 5-5. Crew Elaboration Table—Template

Line Number	Crew ID	Labor	Equipment
–	–	–	–
–	–	–	–
–	–	–	–
–	–	–	–
–	–	–	–
–	–	–	–

To find more detailed information about the crew, go to Crews under Reference Items as shown below and download most updated Crew Standard Union information (Fig. 5-40).

Open Crew Standard Union.pdf; and press **CTRL + F** to open the search box. In the search box, type the crew name and search as shown in Fig. 5-41.

4. Quantity Take-off

According to design details, **perform** quantity take-off for each work item in the lower-level WBS; **present detailed steps** on how you interpret the design for each work item, how you calculate the quantities by the relevant unit of measure, and

Figure 5-40. Download crew reference

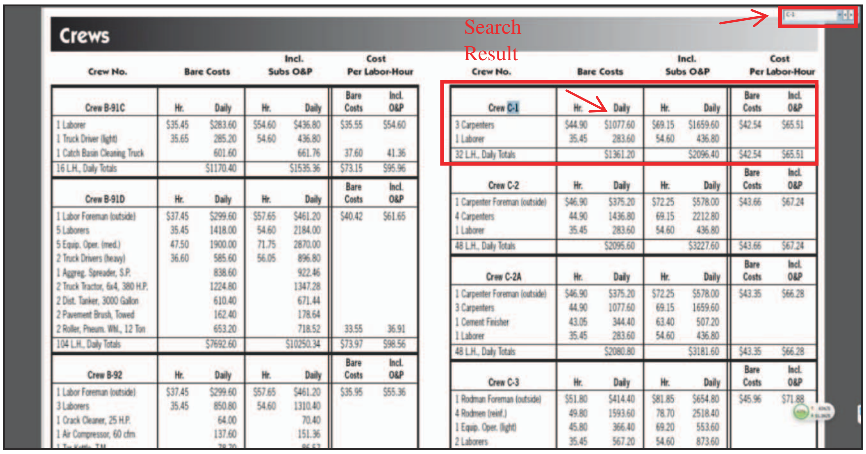

Figure 5-41. Search for crew information

how you address extra quantity of material use based on practical constraints and assumptions. **Summarize** quantity take-off results as per Table 5-6.

Table 5-6. Quantity Take-Off—Template

Upper WBS	*Lower WBS*	*Line Number*	*Description*	*Unit of Measure*	*Quantity*
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–

5. Estimate Direct Cost

Based on RSMeans Edmonton, 2015 data, perform direct cost estimate (bare cost). Use Table 5-7 as a template to summarize cost data. No need to consider indirect cost (overhead and profit), which will be dealt with in an explicit fashion later.

Table 5-7. Direct Cost Estimate Summary—Template

Lower WBS	*Line Number*	*Description*	*Unit*	*Material*	*Labor*	*Equipment*	*$/Unit*	*Quantity*	*Total Material*	*Total Labor*	*Total Equipment*	*Total Cost $*
–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–

6. Estimate Overhead and Profit

Estimate overhead and profit to add to direct cost and derive the total bid price. Samples of indirect costs are given in the following lists. To make realistic estimations, each team needs to make its own assumptions pertaining to indirect cost items and associated amounts and rates as of the date, and those assumptions should be consistent throughout the entire exercise of project planning. For instance, crane cost can be estimated either as overhead/indirect or as part of direct cost, and you are advised against duplicating its effect on project cost. Note some indirect cost items can be estimated as time-dependent, which is based on project duration resulting from scheduling analysis.

Description	*Cost Basis*	*Specific*	*Rate*
Engineering Fees	Current Total	Previous Total Bare	7%
GST	Category	Material	5%
Permits	Lump Sum		\$7,000
Payroll Burden	Category	Labor Bare Total	27%
Insurance	Current Total	Including all above	\$2 per \$1000
Overheads and Profit	Current Total	Including Insurance	18%
Surety Bonds	Grand Total	Two-tier rates based on Grand Total	5% up to \$100,000 2.5% up to \$1,000,000

Assuming the grand total cost (x) exceeds \$100,000, Surety bonds (bid bond) can be determined as the difference between x and Total Excluding Bonds using the equation as follows:

$$[2.5\% \times (x - \$100{,}000)] + (5\% \times \$100{,}000) = x - \text{TotalExBonds}$$

Items for overhead costs considered in the estimate may include "non-pay" items and temp works indispensable to the construction process; examples are:

- Mobilization (installation of fencing around site, installation of utilities)
- Demobilization (dismantling and removal of fencing, cleaning up of site)
- Temporary structures or facilities (e.g., the crane or scaffold cost, if they are not considered in crew cost estimates.)

As for the contingency, your team can assume that it only accounts for a certain percentage (e.g., 2%) of the total base estimate ("Grand Total" obtained above). The contingency percentage estimate, along with possible unknown factors or costs underlying the contingency estimated, need to be addressed.

This part of cost estimate needs to be dealt with in a separate spreadsheet in order to enumerate "what items" and account for "how much for each item."

7. Determine Activity Duration

Determine activity duration for each work item, based on the daily production rate of a crew, Edmonton 2015 obtained from RS Means and your quantity take-off result. Take the production rate as the average performance benchmark under normal job conditions. Your project team needs to provide information and justification if it is necessary to adjust the production rate up or down (e.g., applying efficiency factor less than 1.0; or increase production rate due to more favorable job conditions). The time unit must be hours (not days). Table 5-8 shows a template to summarize information.

Note:

- If the calculated duration is less than 1 hour or is a float, you are advised to round it up to the nearest hour.
- In general, the contractor team considers hiring only one single crew to work on each activity. In special occasions, more than one crew can be applied provided less congested, safe work space is ensured.
- One "work item" activity can be divided into sub-activities, by defining sub-work items for each readily identifiable building component (e.g., CMU Concrete block work item can be divided into CMU Concrete block Wall 1, CMU Concrete block Wall 2, CMU Concrete block Wall 3, and CMU Concrete block Wall 4 for four CMU walls; one crew or more than one crew can be employed to work each sub-work item, allowing certain concurrency in time).
- Construction logic in connection with activity duration estimate needs to be clearly presented in the project report.

Table 5-8. Estimated Duration in Working Hours for Each WBS Item—Template

Upper WBS	*Lower WBS*	*Line Number*	*Description*	*Unit*	*Daily Output*	*Quantity*	*Duration*	*Remarks*
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–

8. Schedule Total Project Duration

For the entire project, sequence the execution of activities as defined in Table 5-8 by writing a statement on precedence relationships, represent project logic in an AON network diagram and perform CPM to schedule the project completion time in hours; schedule start and finish times of each activity (both early and late times); determine the total float and free float on each activity; identify the critical path; plot a bar chart to represent the CPM schedule by showing early times and marking total floats.

The AON project model, along with a statement of construction logic and assumptions underlying the construction logic, should be presented clearly in your bid. You are also encouraged to use sketches or views taken from the 3D model to help with communicating the construction logic statement and AON network diagram.

To do the CPM analysis, it is important to note the following issues:

1. No need to use any CPM software for project scheduling in this case! (P6 can be more distracting and less effective than Excel.)
2. The poured concrete need to be cured before the successor "form stripping" can begin. Curing applies to concreting of wall footing, column footing, slab on grade, column and roof slab. The curing process takes as long as 12 hours in average job conditions. Your team needs to make clear how curing is considered in the project scheduling analysis.
3. The relationships between all activities are Finish-to-Start with the lag time of zero. Your team is advised against using complicated relationships unless you have to.
4. Standard Calendar with 8 hours per day, 5 days per week is applied for all the crews in this project.
5. Project start date is set as March 3, 2015; 07:00:00 am. No working on Saturday and Sunday and Statutory public holidays in Alberta, Canada. Determine the calendar date and hour for the project finish data as per your CPM schedule.

CONCLUSION

The advent of BIM and cloud-based productivity databases in recent years has led to the revisit of long-standing issues in the industry such as design-construction integration and constructability of design, along with a new opportunity to develop an effective framework for integrating detailed estimating and resource scheduling in construction. A critical review of BIM related research sampled from literature has revealed the need to strengthen the foundation knowledge in order to develop construction-centric BIM. A new construction planning framework is formalized with the intention to integrate basic dimensions of construction planning and organize a wide range of interrelated data pertaining to construction engineering and management.

The construction-centric framework shifts the focus of conventional BIM from permanent structure design to temporary structures and construction materials, which are crucial to realize the installation of permanent materials in the construction field and have significant implications on cost, time, safety and quality. Data in relation to methods and resources required for installing temporary structures are defined in the framework. As such, the database underlying a BIM model can be extended to account for all the design and method details relevant to installing both permanent and temporary materials, resulting in a construction-centric BIM model. In the future, in order to facilitate practical application of construction-centric BIM, data and analyses in connection with the formalized construction planning framework can be readily developed into specialized add-in programs on top of Revit. It is hoped the formalized construction planning framework will motivate further research into developing automation tools for rapid, cost-effective BIM modeling, model customization and updating in support of constructor's needs in the ever-changing, fast-moving construction field.

Based on the author's experience teaching a senior construction estimating and scheduling course, many students find it difficult to sketch, visualize and comprehend all the engineering design details that represent the most critical, fundamental steps in construction planning, which generally take place prior to quantity takeoff and cost estimate. In particular, civil engineering graduates with a specialization in construction engineering and management have shown great interest in BIM through learning and applying the newly formalized construction-centric BIM modeling frame to real world challenges in construction estimating, planning and control. Not only does BIM provide impressive visualization of the design in 3D and 2D views conducive to effective communication of a complex, practical problem, BIM models also lend accurate parametric representation of the design, which can be readily expanded to encompass critical data and information relevant to basic dimensions of construction. Through assignments and "design studio" labs, the formalized framework for construction-centric BIM application has been found effective to guide students through takeoff, estimating, and planning processes, and perform "what-if" scenario analyses in arriving at the most cost-effective construction plan. A team project is designed for three students to implement the proposed framework in a more complete project management setting and to integrate the application of AutoDesk Revit and RS Means. The project is detailed planning of construction of a reinforced concrete garage structure featuring concrete masonry unit (CMU) walls based on a structural design BIM model prepared in Revit.

Based on teaching experiments, the proposed framework allows for students to have a better understanding of BIM concept in the context of detailed quantity takeoff, estimating and construction planning. Implementation of the proposed framework on the garage case can reduce the variation of estimation results achieved by student teams in a limited time frame, which demonstrates the effectiveness of the proposed framework in enhancing students' learning. The project specifications and requirements are also enclosed in the Team Project section. (The solution key to quantity takeoff, time determination, and cost estimate can be made available upon request.)

Regardless of the size and complexity of construction projects, engineering processes from design, constructability analysis, detailed planning, and field construction all rely on applying systematic approaches to break down the large project into small sub-projects or work packages of manageable size. The proposed framework provides a roadmap to facilitate construction engineers to account for details in tackling each component of a large project through computer-based, construction-centric BIM applications. It is anticipated if the one-story "garage" problem can be addressed sufficiently, tackling a larger, more complicated project is a straightforward "assembly" process based on a valid work breakdown structure.

It is noteworthy method and material information and cost data in RS Means are on the cloud, but not seamlessly linked with particular design features in BIM; at present, selection of method and material information still largely relies on subjective interpretation of the BIM design details based on engineering knowledge, practical experience, and trade knowhow in connection with construction method applications. In the near future, the ontology-based BIM research along with IPD-BIM integration will continually grow sophistication while enhancing applicability through deeper and further research. It is anticipated that computer could automate the thinking process by today's experienced personnel in construction and would also facilitate the generation of a construction-centric BIM model based on a design-centric BIM model. Eventually, the proposed construction planning framework would well blend into a construction-centric BIM modelling process through integration and automation, giving rise to a futuristic BIM model that would resemble a "cognitive companion" — a new form of artificial intelligence to enable designers and construction engineers.

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