Descriptive Construction Methods through BIM-based Collaboration

Marcel Maghiar\(^1\) and Avi Wiezel\(^2\)

Abstract:

A coordinated Building Information Modeling (BIM) can provide savings to clients in the operating of the building and offer benefits on the contractors’ side. Autodesk 360 is improving collaboration among project members handling architecture, engineering and construction. This paper presents initial results of an effort to establish a consistent methodology to unequivocally classify and quantify construction methods so that they can be embedded in the BIM model. Such classification is referred to as a technology ontology. By introducing rigorous construction method descriptors it is possible to represent, in a matrix, all the available construction methods for any given project. The paper presents the construction method descriptors and a case study to prove the relevance of technology ontology for accurate estimating purposes. Selecting the most appropriate method for building objects can be integrated with BIM in early design phases. Cost savings made on a project through more efficient use of BIM (clear-cut construction methods) can be shared during design and in the same time it can improve collaboration.

Keywords: BIM programs, technology ontology, estimating, construction methods, collaboration

1. INTRODUCTION

The dynamics of the relationship between Architects, Engineers, Contractors, Owners and Operators (AECOO), in BIM context, is the basis for integration between teams of stakeholders in any construction projects. A coordinated BIM approach can provide savings to clients in the operating of the building and offer benefits on the contractors’ side. Horizontal Systems’ BIM programs acquired by Autodesk were rolled into Autodesk 360 improving collaboration among project members handling architecture, engineering and construction. This will enable a BIM workflow from design through construction processes (Autodesk PLM360, 2012). Autodesk’s new cloud-based PLM tool enables businesses to capture and manage product information and processes to continuously improve the created products.

Autodesk PLM 360 supports many of the PLM (Product Lifecycle Management) processes customers expect, such as program and project management, requirements management, supplier management, quality and compliance management. PLM 360 provides a collaboration and data management tool, offering business process coverage, product and project-related applications and lifecycle management of the product. Creating an increased visibility to critical information which most of the time is hindered by an incorrect construction method representation and on top of the building modeling, it grants owners the capability to streamline disjointed processes that create bottlenecks and loss of productivity. Therefore the need of indubitable development for clear definitions of construction method, construction technique and what represent a construction technology was considered by researchers for the past years.

Savings can be generated using BIM, if the design process uses a unique building model through the project lifespan and if the construction methods for all processes are well identified and applied.

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Greater benefits can be found in “Information” in BIM, when the right methods in the construction phases are identified and implemented early on.

The Vico Estimator 2009 provides a unique 3D-model-based estimating system, which comes along with improved accuracy. This is achieved through a user-defined Work Breakdown Structure, and the Conditional Method functionality. Vico Estimator supports large projects by enabling the merging of the quantities of any separate sub-models into one coherent project estimate and by providing comprehensive bid package tools and versioning functionality. Tight integration with the entire Vico Virtual Construction Suite assures model, cost, and schedule synchronization, and allows the clear visual communication of 5D processes.

Vico Recipe Model is enriching 3D model entities with construction Recipe data (Recipe is a breakdown of the Method data). Elements in the Virtual Building model can be associated with costs by assigning a cost Recipe to it. The Recipe assignment is defined as a property in the element’s settings. Another feature of the same modeling software provider, Vico Recipe Link Checker allows for increase accuracy and save time by easily identifying unassigned objects and defining links with the common database. This new feature provides one location for filtering and selecting elements, assigning and changing Recipe assignments. Therefore support for Conditional Methods is enhanced and provides superior integration with Vico Estimator. The Conditional Methods functionality introduced in Estimator 2009 is supported by offering functionality to select properties that are made available in Estimator. Selected properties are written into the common database and can be used with the Conditional Methods feature in Estimator (Vico Software, 2012).

The research effort reported in this paper goes one step further and aims to establish a consistent methodology to unequivocally classify and quantify construction methods. Such classification, called technology ontology, is forming the basis for a consistent and complete representation of the construction methods in models. During the design phase, structural designers can reason on a case-by-case basis how to use specific technologies in a virtual construction environment. During the construction phase of a project, the usage of technologies and specific methods become acute and is essential to the success (in terms of profits) of the overall project. One of the early software tools (SEED-Config) for design environments is intended to assist structural designers in collaboratively exploring and extending the design of buildings (Fenves et al., 2000). A subsystem of this software tool allows for browsing, editing, selecting and applying of “technology nodes” which encapsulate structural design knowledge through “technology tags”, which further stores the name of the “technology node” that was used in designing of a building entity. In this approach, the application of a technology node to a building entity can be interpreted as making one decision about the design solution by refinement (more design details) or by elaboration (decomposing the building entity into new, less abstract building entities).

An approach to support construction cost estimating is through feature-based product models (Staub-French et al., 2002) where features of building components as penetrations, intersections or component similarities (parametric-based or macro features) directly influence the calculation of the construction costs. These features of building components are, in fact, estimator-focused product models and they can be reused from project to project from a given product model. In this sense, feature generator (FeaGen-Staub-French et al., 2002) prototype software was developed to implement the new concepts and to reveal the gain in the level of completeness of estimates generated by practitioners using this tool when compared to state-of-the-art tools. On the other hand, the estimating processes in the residential market exhibit differentiations mimicking the business practices in construction industry. For instance, the trend toward factory-based product bundling and kitting is synthesized in the concept of “Open Building” (Kendall, 2002). This approach divides the entire residential unit (house) process and product in two decisional/technical clusters – Shell (or base building) and Infill (or fit-out) which integrates with the Shell. This design and production method balances the production efficiency and consumer choices in the housing industry.
2. DEFINITIONS OF CONSTRUCTION METHODS, TECHNIQUES AND TECHNOLOGY

An innovative Work Breakdown Structure (WBS) was developed by Oztemir & Wiezel (2003), representing every level of a construction activity, down to the level of intimate details of movements. The generality of Oztemir’s WBS was acquired from a masonry wall building root procedure, as part of an NSF research grant study.

The necessity of clear descriptors for construction methods is revealed in modeling, which will substitute other definitions interpretation and possibility for modeling integration. In essence, a construction method takes into account the type of the work package, which further takes the use of:

A. Resources: materials, labor (crews), equipment, subcontractors, production rates
B. Work Breakdown Structure (WBS), defined through the following breakdown: Project → Job → Operation → Activity → Assignment → Task → Subtask → Action → Movement
C. Responsible party (construction manager, owner, architect, etc.)
D. Constraints or requirements, which are needed to be satisfied before the Work Package can be performed

From jobsite studies, it can be observed that end-effectors are responsible for producing actions. In the same time, materials (that go into the final product) or ancillaries (that do not remain in the final product) are sustaining the deployment of actions. Taking into account all the above considerations, a series of definitions were developed to better understand their descriptive nature in the construction methods when a full model is deployed in design-visualization phase. The terms are described below.

Assembly (product) or Assembly Breakdown Structure (ABS): Property sets of multiple construction objects; Work package: the total number of resources (material, labor-crews, equipment, subcontracting work, production rates) utilized to produce a specific assembly.

WBS: Work breakdown structure is the structure of the process aiming to create a specific assembly; WBS taxonomy: In the taxonomy of the WBS, the breakdown process is as follows: Project → Job → Operation → Activity → Assignment → Tasks → Sub-Tasks → Action → Movements; Levels of WBS taxonomy: According to this structure, the breakdown is generated by relevant changes reflected in: Site → Trade → Assembly → Geometry → Person (Laborer) → Material → Means (End-effectors and Ancillaries) → Face → Stop/Go (movements).

Ancillary: Ancillaries are furnishings and added support materials that do not remain in the final constructed product (assembly). They provide support either for the materials or for the activities taking place. Examples: mortar box, scaffold, concrete forms, nails and ties for false work.

End effector: Device, tool, or part of human body such as hand, acting upon materials, equipment, or ancillaries.

Constraint: requirements that need to be satisfied before or during production of the assembly. Examples: existence of supporting element such as wall frame for installing windows, access path, size of workfront, temperature, humidity, wind, previous work passing inspection.

Construction method: A construction method is a subset of materials or sub-assemblies that go into an assembly and end-effectors, as well as the constraints, needed to produce the said assembly. Applied to the same assembly and having the same constraints in place, one method differs essentially from another method, through the subset of the materials used to construct the respective assembly and the way parts of the assembly (sub-assemblies) are joined for the common purpose of the assembly functionality.

Construction Technique: A subset of the construction method containing a complete set of ancillaries, the WBS taxonomy, and the party directly responsible for the production (mason, crew, superintendent, inspector, etc.) applied to a type of the work package. Applied to the same assembly and within the same method, one technique differs from another technique through the actions, moves and their sequence applied to the work package. In the masonry example above, different techniques within the same method can be considered: single-buttering of the blocks with mortar, double-buttering of the blocks with mortar or pre-buttering of blocks with mortar and laid on the course.

Construction Technology: A collection of construction methods suitable for the production of a building represents a construction technology. When applied to the same building, one technology differentiates
from another through the collection of methods that can be feasible applied to produce the constituent assemblies that function in the building. Related to a masonry example, a pre-stressed reinforced wall built in factory setting is employing different methods in building process than an in-site cavity concrete block wall, so the applied technology is different.

3. TECHNOLOGY ONTOLOGY FOR ESTIMATING – INTRODUCTION

Ontology is a knowledge representation in which the terminologies have been structured to capture the concepts being represented precisely enough to be processed and interpreted by people and machines without any ambiguity. Another general definition of ontology is perceived as the best structure of concepts from a given domain for effective computation (Gruber, 1993). This second approach is the actual focus that started this study, and the authors have had in their minds computational reasons for general definition of ontology.

Ontology for estimating is a knowledge representation in which the terminologies (technologies) have been structured to capture the concepts being represented precisely enough to be processed and interpreted, without ambiguity, by computer models. This knowledge should have applicability and the representation should allow computer implementation.

The development of the ontology for estimating followed these steps:

- Identify key concepts and relationships in estimating: assemblies, work package, taxonomy of WBS, work breakdown structure - WBS, constraints, ancillaries, end-effectors, construction methods, and techniques.
- Produce precise and unambiguous textual definitions for concepts and relationships: all the above concepts have been defined accurately.
- Identify the terms that refer to concepts and their relationships in technologies.

This section is establishing that technologies will add value to the methods selection used in estimating processes and that there is an entire domain for estimate optimization. Estimates become increasingly sophisticated as more time and resources are devoted to developing the scope of the project. The accuracy of an estimate frees it from errors or mistakes. A precise estimate reflects a degree of exactness inherent in the estimating method or the technologies used in the project. With a technology domain (end-effectors, equipment and ancillaries) used in a given project the benefit of it is to save value in contractor direct costs, better utilizing the resources available (up to 60% of total cost) and the cost of estimating (up to 5% of total cost).

4. ONTOLOGY DEVELOPMENT – TECHNOLOGIES

The connection between methods and techniques was introduced previously. Both of them use available resources in a company setting. Activities, which are generated by the changes in geometry of the product (construction object), are required to use methods that are capable of producing the intended product. For example, a cast in place concrete column needs to have forms in place, which can be made of plywood, steel, plastic, or timber. There are different techniques (Table 1) of how to use and attach this formwork: one use, with tie wires, with steel ties, etc.

<table>
<thead>
<tr>
<th>Assembly</th>
<th>Activity</th>
<th>Methods</th>
<th>Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columns</td>
<td>Forms</td>
<td>Plywood</td>
<td>w/ tie wire ,one use</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Steel</td>
<td>w/ tie wire</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plastic</td>
<td>w/ steel ties</td>
</tr>
</tbody>
</table>

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 below (Figure 1):

![Flow chart showing technology breakdown](image)

**Figure 1. Technologies in estimating process**

A method descriptor will have ancillaries, equipment (including tools), and end-effectors. For instance, in activity “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 (3rd uses), power saws, or hydraulic cranes, 55 tons capacity.

In the next section, the method descriptors provide an explicit representation of the available technologies for any particular project and allow the identification of method clusters. Method clusters take into account the possibility of sharing equipment and ancillaries among multiple activities, thus reducing costs. This process, which normally takes place, implicitly, during the estimating and planning of the project, can now be explicitly incorporated into the construction process. Therefore, detailed estimates (unit price and schedule estimates) should take into account technologies along with effective means or methods for consideration of the productivity and quality of the constructed building elements during construction phase in the lifecycle of the building.

To further explain the application of the concept of method descriptors, authors used a simple project as case study. This project will also serve as validation of the concepts presented. From an activity center model, a reinforced concrete slab in the form of a square with 10 feet side and with 5” thickness will be constructed and therefore modeled initially. The slab should be elevated on a bed at 8” mixed gravel. For sewage, it is suggested an underground pipe of 8” diameter, starting from the center of the slab. On the slab structure (Figure 2), four reinforced concrete columns are to be placed at each corner with dimensions of 8”x 8” and with a height of 9 feet.

![Diagram of reinforced concrete structure](image)

**Figure 2. Project example for technology ontology development**
5. CLUSTERS OF METHODS SELECTION FOR OPTIMIZATION

In the considered project, the major phases of construction are as follows:

- Pre-construction phase
- Forms phase
- Reinforcement phase
- Concrete phase

The activities determined to complete the project follow the sequence below:

To represent all technologies involved in this project, all activities necessary to complete the project from a pool of possible activities, materials, equipment, tools and ancillaries that might be available in a construction company setting, were considered. Labor and equipment rates were given by RS Means Construction Cost Data Catalog; also the crews’ daily costs are given. The pool of activities is obtained from Building Construction Cost Data with daily outputs, units and crews. Crew resources, with tools and equipment are also available. Materials and ancillaries are calculated, crews and their costs can be provided, and the calculation for consumption corresponding to labor and equipment for each individual activity can be determined. Based on the calculation of consumption for labor and equipment for all considered activities, these activities were selected as they were described above in estimating the project. The estimate takes all equipment, tools and ancillaries corresponding to each activity and phase of construction. The consumption of each method descriptor is summed and a general number is obtained based on unit quantities of every element from method descriptors (Figure 3). An “x” is marked, in Figure 3, whenever the equipment, tool, or ancillary is used in one of the activities. Based on the sequence suggested to complete the project, the method descriptors are rearranged in an organized fashion to correlate the activity description with method descriptor (Figure 4). There are five possible alternatives for selecting the right methods based on method descriptors. These are called “clusters of group alternates for methods”, and they make the domain for optimization.

![Figure 3. Method descriptors for technology ontology development](image-url)

For example, looking at the matrix of alternate methods for this particular project in Figure 4, for concrete activities, the user can elect different technologies, like: direct chute, concrete pump (small), crane - 80 tons and tools, gas engine vibrators, hydraulic crane - 55 tons or concrete bucket - 1 C.Y. Four of these
can be used for pouring concrete in slabs and four of them can be used for pouring concrete in columns. The user should pick-up one for each activity. Therefore, the utility of the domain for optimization is proven (use of one technology for multiple activities, select technologies to be brought in site for low-cost considerations and fitted for activity, etc.)

6. DOMAIN FOR ESTIMATE OPTIMIZATION

Technologies available in a company setting would add value to the methods selection used in estimating processes. The totality of these technologies and the resource allocation make up the domain for estimate optimization. In the given case study there were five possible alternatives for selecting the right methods based on method descriptors, but these clusters of group alternates for methods can be broken down in different arrays, derived from the purpose of the optimization, as explained below.

Referring to clusters of group alternates for construction methods, the user should elect one method for each individual activity, using one of the technologies available for multiple activities. Through method selection, technologies for the site are selected. For example, in Figure 4, 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.

The domain of estimate optimization is relevant through the existence of the matrix of alternate construction methods for a given project and establishment of clusters of group alternates for all possible construction methods.

<table>
<thead>
<tr>
<th>Nom.</th>
<th>Method descriptor</th>
<th>Pre-construction</th>
<th>Forms</th>
<th>Reinforcement</th>
<th>Concrete</th>
<th>Total Direct Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Activity/Descriptor</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>Backhoe Loader, 48 HP</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Alt_1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Dozer, 75 HP</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>On chairs - before gravel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Open trenchless - on ground - after gravel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>HDD w/porous concrete pipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>HHD w/Corrugated metal pipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Fiberglass for forms (no. of uses)</td>
<td>Alt_3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Plywood for forms (no. of uses)</td>
<td></td>
<td>Alt_4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Metal forms (no. of uses)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Ties with plastic spacers - on site</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Welded on chairs - in factory</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Alternates for project estimate optimization

7. CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

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 and a specific technology built within the estimate, and recalled from various databases of the model estimate, is beyond the scope of this research. Once details of relationships are known, construction methods and available technologies may be automatically aggregated and computationally integrated into activities, therefore the whole
Construction process can be optimized for time, cost, quality, or safety. These considerations may be assigned as information in the developed models and analyzed by the BIM staff, as early as during the initial design phase.

Another recommendation for further work is the actual domain of estimate optimization. The optimization of the estimate, based on the technology ontology, was not driving the purpose of this research. However, a series of new research opportunities, pertaining to the scope of optimization in the information models, may present valuable savings to companies in the construction industry.

REFERENCES


