Investigation of Leveraging BIM Information Exchange Standards for Conducting LOD-Based Cost Estimating

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ABSTRACT

Building Information Modeling (BIM) is a digital information management system that can facilitate workflows and delivery of information in facility projects. Cost estimating is one of the uses of BIM that has the potential to reduce considerably the time and cost required for estimating construction cost of a building project. In this use, type of materials along with their quantities and properties are extracted from building information models and mapped to a cost estimating database in order to estimate the cost. However, interoperability issues currently exist in the industry for the exchange of information from BIM authoring software to cost estimation tools impedes reaching to the full potential efficiency in this use. This paper identifies common information exchange workflows between BIM authoring and cost estimating tools and discusses their advantages and issues. It continues with studying potentials in leveraging open information modeling standards for addressing the identified shortcomings in the workflows. Next, a Level Of Development (LOD)-based cost estimating framework is proposed that uses open information modeling standards for addressing inefficiencies in different detail levels of cost estimating approaches commonly being practiced in the industry. This framework facilitates automated digital information exchanges in the process of using BIM for cost estimating and promotes the implementation of BIM-based cost estimating from early stages of projects.

Keywords: Building Information Modeling (BIM), Cost Estimating, Level of Development (LOD), Industry Foundation Classes (IFC).
INTRODUCTION

Building Information Modeling (BIM) is one of the trending technologies in the construction industry as its adaptation has tripled in usage during the past decade and it still continues to grow (McGraw Hill Construction 2012). It is a technology that is not just a set of software but also a process, where it can assist with workflows and delivery of information throughout projects in the Architecture-Engineering-Construction (AEC) Industry (NIBS 2012; Ramaji, Memari, & Messner, 2017). Cost estimating is one of the most desired BIM uses among construction companies in which building information models are used for taking off quantities and then linking them to cost estimating databases. In the traditional methods of cost estimating, quantities are taken off using a printed set of drawings provided by the architects and engineers, and are then manually input in a worksheet along with related unit costs (Shen and Issa 2010). This process is usually improved by leveraging CAD-based files along with on-screen quantity take off tools such as PlanSwift, Bluebeam, Autodesk QTO, etc. In such workflows, drawings sets provided by the architects and engineers are scanned and then collected data are exported to a worksheet where the total cost is calculated by manual mapping between unit costs and extracted quantities.

BIM, as an integrated information management, can facilitate estimating construction cost from early stages of projects. As a result of the shift in the industry toward more integrated project activities, especially in Design-Build and Integrated Project Delivery (IPD), the need for estimating construction cost from early stages of projects is increasing (Rowlinson and Rowlinson 2017; Sunil et al. 2015). A preliminary cost estimation at early stages of design can very quickly develop into a fundamental guideline that determines feasibility of a project, and also become a main parameter with which the design has to conform throughout its development. (Wu et al. 2014). It also plays an important role in financial management of project, where it determines the profit or loss factors. In addition, even though cost estimating is only an approximation of cost of the project, a concise cost estimating plays a significant role in competing for the contract and winning the bid.

Cost estimating is one of the several applications of BIM. According to a McGraw Hill Construction (2012) report, its value-over-difficulty ratio is very low (negative 13%), which means generally it is more efficient to use traditional cost estimating methods compared to leveraging building information models for this purpose. According to (Sabol 2008), such inefficiency is because of the complexities in the exchange of information from building information models to cost estimating tools/databases. Application of BIM for cost estimating at early stages of design, when detailed quantities and dimensions are not considered, is even more challenging (García de Soto et al. 2017). There is no standardized set of parameters for approximate cost estimating; as a result, extraction of required information from building information models and transferring it to approximate cost estimating platforms is complex and requires extensive manual data manipulation. In spite of such complexities and shortcomings currently associated with BIM-based cost estimating, it still has several benefits over traditional methods (Azhar et al. 2015). For example, although a BIM-based cost estimating might not reduce the overall time of the activity, it reduces errors by automating the quantity take off process. In addition, even if BIM-based cost estimating requires an estimator to put effort and time to conceive building information models, it saves time later in the project, when designs are complete or modified as a result of a request for changes (Sunil et al. 2015). This could be a very valuable characteristic in Design-Build and IPD.
projects in which cost estimation occurs frequently as a design progress throughout the project (Porwal and Hewage 2013).

In the research reported here, potentials of the industry information standards for addressing complexities of BIM-based cost estimating is studied. Information requirements for cost estimating at each stage of projects are different; to clarify such differences, various levels of cost estimating are discussed in the following section. Next, overall workflows for exchange of information from BIM authoring software to cost estimating tools are investigated as well as issues associated with each workflow. Afterward, it is investigated how construction industry information standards can be utilized to address shortcomings that currently exist in this BIM use.

LEVELS OF COST ESTIMATING

Cost estimating is an important factor that can significantly affect design and construction planning in facility projects, thus it needs to be performed multiple times as a project progresses. In collaborative project delivery methods, such as Design-Build and IPD, numerous cost estimating analyses are conducted repeatedly to ensure a project is on track in terms of budget. The result of cost estimating analysis gets more concise as design progresses and more detailed information becomes available. Therefore, considering level of development in a project, different levels of cost estimating can be carried out (Wu et al. 2014). According to literature, based on the leveraged details in cost estimating, three main levels of estimating can be defined: preliminary, product-based, and process-based, which are discussed in the following (Cheung et al. 2012; Christensen and Dysert 2011; Deshpande 1999; Sabol 2008; Wu et al. 2014):

**Preliminary Estimating:** This level of cost estimation can be carried out as early as the schematic/conceptual design phase, when the architects and maybe engineers have only designed a building based on the general project scope the owner has asked for. Number of stories, location of the project, and square-footage of the building are a few examples for the information being used in such estimating. Preliminary estimates are usually conducted based on the past experiences and databases that a company keeps record of. Such knowledge is usually classified in different categories such as type of the building, square footage, energy standards being used in the building, etc. (Cheung et al. 2012). The first level of estimating is mainly to determine if the project is feasible financially. Another use for preliminary estimating is preparation and evaluation of proposals in Design-Build projects. BIM does possess the capabilities of using a simple model to accommodate the goal of simply determining if the project is feasible financially. Level Of Development (LOD) of building elements and assemblies in such level of estimating is low. Objects and components at this level are generic, and will be most likely developed in more detail later in a project as the design progresses (Sabol 2008).

**Product-Oriented Estimating:** A detailed estimating can be conducted after a preliminary design is completed, and be frequently refined until construction documentation sets are generated. Cost estimating at this level is based on individual objects and assemblies in a building in which level of development is increased throughout the design stages (Sabol 2008). Estimating cost of a design in order to bid for a project is one of the uses of this level of estimating. By leveraging BIM for this purpose, one can define objects in more details, increase accuracy of quantity take offs, thus, enhances the quality of the cost estimation.
**Process-Oriented Estimating:** This level of cost estimating is used when more information about the process of construction activities is known and a higher level of accuracy is required in predicting construction cost of a project. Such type of estimating is usually performed once a contract is awarded or the contractor is short listed. At such stage of a project, there should be minimum errors to none in forecasting the final cost of the entire project. This is when a construction company can predict the process of making building element from their materials and has the opportunity to negotiate contract type of the project (Deshpande 1999). At this level of estimating, the highest level of development in the input building information models is required in order to show the most detailed element attributes. This leads to accurate costing for future referencing and as-built accuracy. Based on a research conducted by Christensen and Dysert (2011), the preliminary cost estimating is generally used at 0% to 40% of project completion and is only rated between a 1 and 10 in difficulty; the product-oriented estimating is usually performed at around 10% to 70% of project completion and is rated between a 3 and 20 in difficulty; lastly, the process-oriented estimating is conducted when a project is at least 30% complete, and is rated between a 5 and 100 in difficulty (Sabol 2008).

**BIM COST ESTIMATING WORKFLOWS**

In order to leverage BIM for cost estimating, a building information model of the facility is required. Such model could be either created for this purpose, or more efficiently be turned over by the architects and engineers of the project. Regardless of the author of the building information model, accuracy of BIM-based cost estimating heavily depends on the quality and accuracy of the input building information models (Wu et al. 2014). Such model can be developed in one of the many BIM authoring tools available in the industry such as Revit, Vectorworks, ArchiCAD, etc. In the process of using BIM for cost estimating, physical information of building components and their attributes needs to be mapped to a cost database. In such databases, different components and activities that are common in construction projects are itemized and assigned with a unit price. To estimate the cost, one needs to identify items that best represent the building component in the building information models, extract their unit price, and multiply them to the quantity of elements. In the BIM-based cost estimating, this process can be handled with three different approaches, which are discussed separately in the following:

**Manual Data Mapping:** In this workflow, once a building information model is created and turned over by an architect or engineers, quantity of the building components is extracted using BIM authoring tools or any other alternative tools. The extracted data of quantities are then exported into a quantity data worksheet such as Excel. Next, quantities are manually input into a cost estimating tool, which pulls cost from a cost estimating database, such as RSMeans or Sage Estimating. Another approach in this workflow is identifying the unit price of each component based on a cost database, and then inputting them in a worksheet manually in order to multiply them by their quantities and calculate the total cost. One of the disadvantages of this workflow is that it is a very time-consuming process as many data mappings and information transfers need to be handled manually. Such approach is also susceptible to human errors. Another complexity with this approach is updating an estimate after design changes. When a revised set of drawings are released by the architect or the engineers, it is very tedious to track changes in the quantities and types of the building components. This type of estimating best suites the preliminary cost estimating, where level of details is low and only a few number of factors and parameters are used
for cost estimating. In spite of the difficulties associated with this workflow for higher levels of cost estimating, it still has several advantages over CAD-based cost estimating workflows. Higher accuracy of quantity take off, quicker data extraction process, and more integration in the resulting information management system are a few examples for such advantages. However, these characteristics speed up the cost estimating process if a building information mode is available. Otherwise, it might be more efficient to go with the CAD-based systems rather than developing a building information model only for purpose of facilitating quantity take off.

**Cost-Loaded BIM:** The second workflow is to assign cost as a property to building components manually while a model is being created in a BIM authoring tool. Many of the BIM authoring tools can input such attributes and store the cost information along with the physical information of a model in order to calculate total cost of the project. Using such information, they also can produce a detailed budget or bidding report. One major issue with this path is that cost fluctuates and one must continuously update the cost attributes assigned to the objects. Handling this issue becomes more challenging in large constructions, where it takes a few years to complete the project. Inappropriate maintenance of the cost attributes in such projects might lead to misleading cost estimation results. As Mostavi et al. (2017) argue, having inaccurate information at a wrong time can result in incorrect decision making and unrealistic project planning. This approach for cost estimating suites best the product-oriented cost estimating, where the number of components is high enough to make sense of using BIM for facilitating the complexities of cost estimating; whereas, cost attributes are not being frequently updated as unit costs are approximate and results will be used for immediate decision makings such as biddings. In such timeframe, small changes in the approximate values of the unit cost can be ignored as the time period between assigning the cost attributes to using them for decision making is short.

**Linked Databases:** The third workflow can be accomplished by linking BIM authoring tools with cost estimating databases for automated data-mapping. Due to the lack of standards, such links currently available in the industry are mostly proprietary and are implemented via add-ons. This type of workflow significantly reduces required manual activities and as a result increases quality of the estimating. In addition, as a result of automated data mapping, it will be much a quicker process compared to manual data mapping and cost-loaded BIM workflows. Furthermore, because of the linked databases, updating unit cost of the BIM objects is swift and autonomous. However, there are some shortcomings associated with this type of workflow. A high-level cost estimating is usually performed at or after the design development phase, when different aspects of a building are designed by different disciplines. In such cases, there is a possibility that not all the parties use the same BIM authoring tool for creating their discipline-specific building information model. In this situation, building information models cannot be merged in order to take benefit from such links. Although, there are some possible processes for transformation of a building information model to another format, but that process is highly error-prone and might lead to data loss or redundant duplication of objects. In addition, any updates that are pushed for BIM authoring tools or the cost estimating tool might not be compatible with the link. As a result of using proprietary data structures, version change management of the links between BIM authoring tools and cost databases is tedious and expensive. This major interoperability flaw can lead to miscommunications between the two tools as well as inaccurate transfer and loss of data. This workflow works best with process-based cost estimating, where there is a high level of detail in the building information model and unit price needs to be updated frequently throughout the project.
FACILITATING THE PROCESS USING INDUSTRY STANDARDS

Cost estimating is one of the BIM uses that includes several information exchanges between two types of tools/databases that are different in nature. BIM contains hierarchical models that can include geometry and complex relationships between different objects. On the other hand, cost estimating databases and tools use flat data structures that only induce a list of items, prices, and their quantities. Therefore, mapping data between such data structures is challenging. Such complexities is one of the reasons for low interoperability in this use of BIM. Information exchange standards can facilitate such data mappings by providing a common language and reference points for the construction industry. In the research reported here, a new framework is developed that leverages such standards for enhancing interoperability in the cost estimating use of BIM. The overall workflow results by implementation of this framework is shown in Figure 1. The process starts with creation of a building information model in a BIM authoring tool, and follows by exporting an Industry Foundation Classes (IFC) file. In this framework, the Design Transfer View is used as the Model View Definition (MVD) for IFC files as it contains the majority of the concepts needed for carrying information required for cost estimating and is being officially maintained by buildingSMART International. The IFC file is then imported to a cost estimating tool that contains cost databases structured based on a n information modeling standard. In the cost estimating tool, a desired level of estimating is inquired from the user, and required Level of Development Standard (LOD) in the IFC file is identified accordingly. Based on the mapping between LODs and IFC objects, required information is extracted, followed by mapping them to a unit price item with the same LOD for each object. Considering the automated data transfer and data-mapping between BIM authoring and cost estimation in the framework, it can be classified in the Linked Databases category of workflows.

Figure 1. Overall workflow of the framework

As an example for cost estimating using the developed workflow, when construction cost of a wall is being estimated, the input IFC file of the building is imported. Then, LOD of the wall element is queried. The available reliable information could be limited to overall area of the wall, or additionally include information related to the type of the wall element (e.g., shear wall, plumbing wall, and composite wall). If the additional information is available, then a unit price for
that specific type of wall is extracted from the cost database and mapped to the area of the slab in order to calculate the construction cost. If the information is not available, then a unit price for generic walls is inquired and used for cost estimating. The input model might have a high LOD in which the exact quantities and sizes of the elements composing the wall are available. In this case, quantities of the composing materials are extracted and mapped to unit prices of the materials in order to calculate the construction cost of the wall more concisely.

The overall schema of the framework is shown in Figure 2, in which LOD standard is used as a common language between building information models and cost databases. The Level of Development (LOD) Specification is a standard that enables different parties to clearly define reliability of the content of building information models at different stages of building projects (BIMForum 2016). However, since this specification is written in a human readable language, it cannot be directly used for the exchange of the digital content of building information models and cost databases. Such standard is used in the framework for mapping the data structures of these two types of tools/databases. There are many proprietary data structures for each of the two types of database/models, many of which are being continuously updated. Without standards for digital representation of information, development and maintenance of interoperable information exchange framework is expensive and convoluted. The framework developed in this research leverages current industry standards to address this issue. The following subsections discuss how the framework benefits from these standards.

Standards applicable to BIM

There are several open standards in the industry that are developed for digital representation of building. The CIS/2, gbXML, and Industry Foundation Classes (IFC) schemas are a few examples for such types of standards. Among these, IFC is the best choice to be used for carrying information in the cost estimating BIM use as it is capable of representing detailed geometry of building elements, is widely implemented in the BIM tools, and includes numerous concepts for representation of a wide variety of objects being used in the building industry. Therefore, IFC is selected as a standard format for the exchange of information from BIM authoring software to cost estimating tools. IFC was developed in 1994 by buildingSMART alliance to address the need of the building industry standard for 3-Dimensional (3D) digital
models of different types of buildings, and has been continuously updated since then (Ramaji et al. 2017a). In the workflow, information models need to be exported to IFC files in order to pass the building information to an estimating tool for extraction of the information required for cost estimating. Since LOD standard is used as a common language between building information models and cost databases, a data mapping is required between various standardized levels of development and different IFC objects that carry the information units required for cost estimating. Such data mapping is being carried out in the ongoing research being reported here and the results will be reported in future publications.

**Standards applicable to cost databases**

Cost databases have very flat data structure that consist of a breakdown of building components, materials, and activities along with their unit price. Due to the simple structure of such databases, many of the text-based standard file formats such as XML and CSV can be and are being leveraged for digital representation and exchange of information. However, the complexity in the information modeling of cost databases is in the breakdown structure of the components, materials, and tasks. In some parts of the world, unit prices are determined by governmental agencies. In such cases, the information hierarchy that the government defines serves as a standard for the tools that implement such regulated cost databases. However, in North America, there is not a standard cost database or a standard breakdown of items. Nonetheless, there are some standards in the industry that are developed for organizing information related to construction projects, including cost databases. UniClass, OmniClass, MasterFormat, and UniFormat are examples for such standards. Since standards are not proprietary and are publicly available at a small or no cost, they can be used as set-in stone for defining the hierarchy of building information in a human readable format. Such standards for information hierarchy breakdown a building project from different perspectives like organizational roles, building physical components/assemblies, services, and work results. Depending on the level of estimating, one can choose one of these standards that best serve the available reliable information in the project. Having standards in the industry can potentially address interoperability issues; however, providing too many options for each type of information molding and model exchange standards might have an opposite effect. Although MasterFormat and UniFormat are the most common data structures being used in North America for cost estimating, they can only address detailed cost estimating. Since the framework presented in this paper is developed to address cost estimating from early stages of design, OmniClass tables are adopted as the basis for creating cost databases as it is an open standard that has a large scope and addresses many different aspects of projects that are required for different levels of cost estimating. Due to the differences between information requirements in each level of cost estimating, a different structure for cost data is required for each level. In the following, the OmniClass tables that are used for each of the levels are discussed.

*OmniClass Tables 11 and 12 for Preliminary Level:* unit prices need to be formulated based on the high-level overall properties of buildings such as square footage, overall shape of the building, and type of structural system. OmniClass Tables 11 and 12 breakdowns construction entities by, respectively, functions and forms. In this framework, cost databases are structured based on the items documented in these tables. As shown in Figure 2, these items are not labeled with LODs as they are all high-level concepts that can be related to objects with LODs 100 and 200. Labeling these tables to LODs does not add much value to the framework and would make it unnecessarily complex.
OmniClass Tables 21 for Product-Oriented Level: At this level, cost databases need to contain items representing physical elements and assemblies that might be used in a building. Depending on the LOD of the input building model, building systems and assemblies may be broken down into more details. Therefore, in cost databases being used at this level, cost items need to be labeled with LODs. This enables cost estimating tools to map each object to a right cost item considering its LOD. To address this, OmniClass Table 21-Elements is used in the framework for structuring cost databases used in the product-oriented estimating.

OmniClass Tables 22 for Process-Oriented Level: In order to achieve a more concise and detailed forecast, cost estimating need to be performed based on the components of building elements and the process of their construction. Therefore, at this level, a cost database is required that includes detailed components and materials of various building elements. To address this need, the framework leverages OmniClass Table 22 for this level of estimating. This table includes common construction entities that might be constructed after all required raw materials, required labor and equipment, and processes have been incorporated (OCCS 2017).

Although the framework uses various OmniClass tables for different levels of estimating, the LOD labeling of the items in these tables makes it possible to do any intermediate level of estimating in the spectrum between product-oriented and process-oriented cost estimating. This is feasible as a result of having LOD labels as a decision-making criterion for selecting an appropriate table for estimating cost of each of the objects included in the input building information model. However, such capability depends upon availability of two cost consistent databases structured based on Tables 21 and 22.

SUMMARY AND CONCLUDING REMARKS

This paper has investigated application of BIM in estimating cost of facility project from early stages of design to the end of the construction project. Three levels of cost estimating are identified that might be carried out in a project depending on the completion percentage of design, contractual stage of the project, and available information: preliminary, product oriented, and process-based estimating. Three possible categories are defined for the BIM-based cost estimating: 1) manual data mapping, 2) cost-loaded BIM, and 3) linked models. The latter category is the most efficient potential workflow. However, due to the current shortcomings in the industry, full implementation of it is either impossible or limited to proprietary tools, formats, and databases. This paper has reported results of an ongoing research that has proposed an LOD-based framework for addressing interoperability issues in the cost estimating use of BIM. It shows how industry’s open BIM standards can enable cost estimating with respect to the level of development of BIM models. IFC, LOD Specification, and OmniClass Tables are the standards that are used in this framework. Implementation of the framework leads to automated information exchanges and data mappings between BIM authoring software and cost estimating tools.

In the next phases of research project reported here, data mapping between standardized LODs and IFC concepts will be carried out, which will also lead to identification of possible shortcomings in the IFC schema for carrying all the information units required for cost estimating. In addition, a similar cost data mapping needs to be carried out between standardized LODs and the items included in the leveraged OmniClass tables. Furthermore, efficiency of the proposed framework will be examined by means of a case study.
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