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A Framework for Model-Based Estimating in Preconstruction: A Scalable Approach

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The preconstruction field has struggled to adopt model-based practices and often lags behind in implementing similar BIM-based workflows in the construction industry. Model-based estimating practices provide a mechanism to increase efficiency and improve the overall preconstruction process. However, even as rapid growth in technology continues, current barriers to adoption persist, and the industry is challenged to educate and train the workforce to use these technologies effectively. A simplified model-based estimating framework must be identified and standardized to solve these barriers to adoption. This paper proposes a framework supporting a software-agnostic, standardized BIM-based workflow for preconstruction called the Integrated Estimating workflow, which relies upon five categories: 1) Intentional Model Authoring, 2) Qualitative and Quantitative Data, 3) Integration of Cost, 4) An Estimating Standard, and 5) Application of Automation or Augmentation to either parts of or the whole process. The significance of this framework is to identify an uncomplicated, but standardized model-based estimating workflow, and to create an identifiable distinction between this workflow and others commonly referred to as model-based estimating workflows.

Key Words: Model-Based Estimating, Preconstruction, 5D BIM, Standardization

Introduction

The construction industry has been plagued by inefficiency and is frequently cited as having the lowest productivity levels compared to other major non-farm industries. While the construction industry is the largest by spending, as measured by global gross domestic product (GDP), it is the lowest performing from a productivity standpoint and is also the least digitized industry (Ribeirinho et al., 2020). Building Information Modeling (BIM) is well-known and generally appreciated as a tool for digital disruption in the industry (Arifin et al., 2022). Within the Architecture, Engineering, and Construction (AEC) industry, BIM gained momentum in the late 2000's and early 2010's, and adoption of technology and digital transformation projects abound today. BIM continues to provide many promises to the industry and is still early in its maturity and in terms of its potential to yield cross-disciplinary benefits. However, the preconstruction sector of the industry has arrived on the scene almost twenty years later than many other industries (Arifin et al., 2022).

Preconstruction has been slow to adopt BIM. For most estimators, it is often viewed as part of a secondary toolkit, and not the primary tool of choice. The field of preconstruction stands to benefit by adopting BIM as part of the estimating process. Particularly in the area of quantity takeoff efficiency, design comprehension, and estimating accuracy, but also in terms of collaboration with other disciplines (Borhani et al., 2018). Industry-related software has also matured to a level that it can support the challenges found in preconstruction. Furthermore, the integration and collaboration between the design profession and the preconstruction world are increasingly becoming more collaborative (Borhani et al., 2018; Ribeirinho et al., 2020). Lastly, the education and training of estimators are shifting to a point where the adoption of more technology-centered toolkits is possible. For instance, as academia prepares students to be industry-capable employees, standard practices help create a trained workforce ready for practice, in lieu of having to learn and support a diverse set of tools and practices (Borhani et al., 2018).

Hence, this paper introduces a simplified framework that supports the adoption of BIM for use cases inside preconstruction workflows. The first iteration of the framework's concepts was proposed in 2020 for consideration by professional practice (Pilgrim, 2020). The paper argues further for a clear definition for BIM-based estimating workflows. Generally referred to as model-based estimating (MBE) or "5D-BIM", the concepts put forth in this paper clarify the definition of this workflow, which represents a research gap important to advancing the implementation and scalability of these practices in the industry (Koutamanis, 2020). The proposed framework also addresses current barriers to adoption and challenges faced by teams implementing MBE workflows. As a result, this framework is intentionally software agnostic and does not endorse a particular software product so that users can achieve success with a variety of available software applications.

Literature Review

This section will demonstrate what previous research has accomplished, highlighting many of the known barriers to adoption, identifying the need for clearer terminology in MBE workflows, as well as the basic need for the proposed workflow. To date, MBE, and other uses of BIM in the preconstruction phases of a project rely on ad-hoc strategies to be successful. Ad-hoc, in this case, means to improvise (Merriam-Webster, 2023). This is evident in the way proposed methodologies in other research offer various approaches to dealing with uncertainty found in model quality and the guidance provided on model conditioning activities (Borhani et al., 2018). Ad-hoc strategies are needed because of a lack of formalized, industry-wide, accepted practices, or standardization for BIM-based workflows (Vigneault et al., 2019). In short, current MBE workflows have not matured to a level the industry finds practical and reliable enough to encourage widespread adoption (Borhani et al., 2018). However, the industry generally accepts the premise that MBE affords value and opportunity but lacks a standard approach that is scalable and repeatable. These challenges are reflected by previous studies that indicate, "*An integrated solution for providing the information inputs and data streams to BIM is needed for the efficient functioning of 5D modeling*." (Mesároš et al., 2019, page 2).

The terminology around MBE, which is not clearly defined or universally accepted, is one of the factors affecting the standardization of the workflows. The terms used in practice today are ambiguous. For example, MBE is sometimes referred to as "5D" or "5D BIM," which is a disputed term and often considered too kitschy to serve as an officially recognized label (Koutamanis, 2020). Even as BIM was maturing, the industry recognized the need to establish a clear definition of what constituted true building information models, and eventually, a definition was established (Eastman et al., 2008, as cited in McCuen, 2015).

The same is now true for MBE workflows. Koutamanis argues that the terminology is significant and matters. Koutamanis (2020, page 1) states, "*one should question not only the incremental addition of dimensions to BIM but also the extended usage of the term 'dimension' in building representations: is it meaningful and correct?"* Koutamanis suggests "3D" is intrinsic to the definition of a model object and requires no justification in terms of dimensions, and that time is appropriately cited as the fourth dimension (4D) since it establishes the history of an object. However, Koutamanis argues because cost, such as unit prices, is not "essential for the identity of objects", cost cannot be a "dimension" of BIM, but rather, it is a property or characteristic of a BIM object. At the same time, others in the industry generally accept that the terms "5D" and "5D BIM" refer to the combination of three-dimensional geometry and cost data (Kamardeen, 2010, as cited in Smith, 2014). Still, some definitions go further and imply that "5D" workflows include the ability to link cost from the estimate to the model data itself (Vigneault et al., 2019). Therefore, the ambiguity around MBE workflow terminology could lead to legal or contractual disputes in terms of performance expectations and the solicitation of BIM or preconstruction services. These findings expose a research gap and suggest that terminology is needed in distinguishing workflows that allow a manual transfer of quantities (disconnected) from one application to another versus those workflows that require a direct link to the item quantity.

Other challenges to the adoption of MBE relate to users' experience in practice. These practical issues become stumbling blocks to successful implementations because they prevent scalability or discourage repeatability. Previous research has identified a range of issues, such as model consistency, model quality, modeling standards, variations in Levels of Development (LOD), classification and nomenclature issues, estimating standards, software features and functionality, automation issues, and skills and training issues (Mayouf et al., 2019; Flynn, 2018; Goucher et al., 2012).

Some research has also focused on challenges with MBE workflows that deal with software limitations, platform interoperability, and data exchange formats (Sabol, L. 2008). While important issues, these aspects were more limiting when software platforms were less mature. In general, technology-related issues will likely be overcome with the maturation of software itself. Other studies recommend key requirements for cost modeling using BIM. These recommendations focus on aspects that do not help to create a standard for industry-wide adoption and assist in implementation strategies, but rather deal with issues that were significant earlier in the maturation phase of BIM, such as being able to import a model and visualize 3D geometry (De Silva et al., 2013). Some of these key requirements are no longer true barriers to adoption, and as noted above, our current barriers deal with other practical challenges. This research aims to answer what specific categories should now be considered in defining Integrated Estimating workflows. The development of the Integrated Estimating framework relies upon the five categories, discussed in the Methodology section, that offer a simple, scalable, and repeatable solution to overcoming current adoption barriers.

Methodology

In addition to reviewing past research, the proposed framework is based on reviewing estimating practices from more than 15 years of practitioner-level experience using a successful MBE process. Previous work experience includes various projects covering a wide spectrum of market sectors and project types. The first author's practical experience involves the use of a proprietary software called, DESTINI Profiler, and DESTINI Estimator, with secondary exposure to generalized MBE workflows using other tools, such as Innovaya, Assemble, VICO Office, RIB iTWO, Revit, and Timberline.

A comparative review of the MBE practices using DESTINI versus general model-based workflow practices identified basic activities within two main phases of MBE workflows. The first phase is the model-authoring phase. The second phase is the estimating phase. A brief description of these phases and activities is explained below.

- In the model-authoring phase, model authors created model content that reflects the design intent of the project and commensurate to the design phase. The model objects contained proper identity and measurable data. In DESTINI, the software ensured this data was present.
- In the estimating phase, quantities were extracted from the model to correlate cost items in the estimate. In DESTINI, the software provided a digital "link" to the quantities and even automated cost mapping to specific model objects.

From the evaluation of these two phases and respective activities, five areas were identified in which MBE workflows either fail at scalability and implementation or support the adoption of the workflow. The categories are: 1) model authoring, 2) qualitative and quantitative data, 3) linking cost to quantities in the model, 4) use of an estimating standard to deal with varying LOD, and 5) automating parts of or the whole process. These five areas become the focus of a new framework called the Integrated Estimating framework.

Proposed Integrated Estimating Workflow Framework

This study introduces the Integrated Estimating workflow as a framework to i) define and distinguish a workflow that offers an uncomplicated, but standardized solution to the industry, and ii) deploy MBE in a software-agnostic environment and using a wide variety of tools. This section explains the framework. The Integrated Estimating framework focuses on the five identified areas to distinguish it from other MBE practices. The framework codifies these areas into characteristics that when combined together, create a unique workflow that addresses the most common model authoring and estimating challenges encountered with other ad-hoc style MBE workflows. As a codified framework, Figure 1 shows the characteristics of the framework and demonstrates their relevance to solving current adoption challenges.

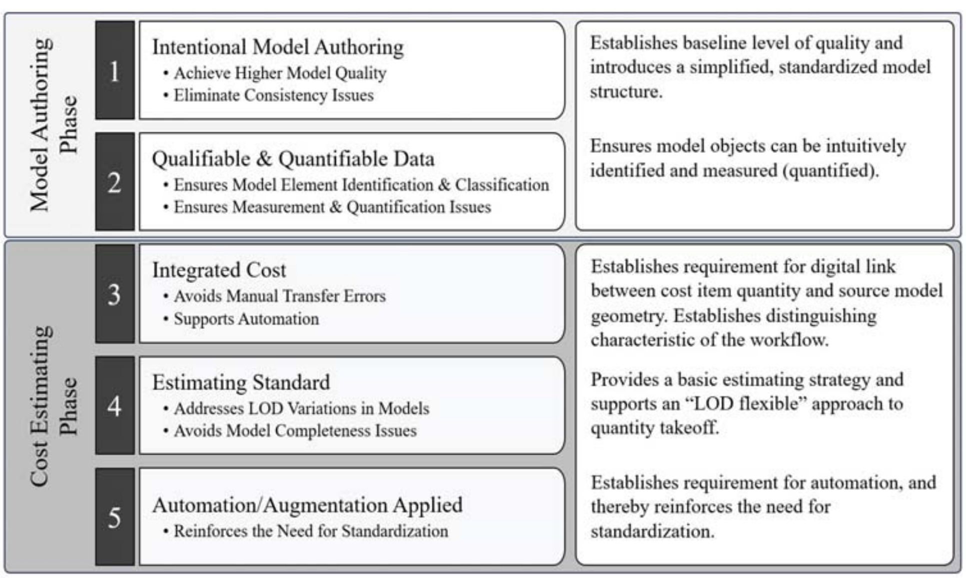

Figure 1. Integrated Estimating Framework: The Five Characteristics and Barriers Addressed

The five characteristics become 1) Intentional Model Authoring, 2) Qualitative and Quantitative Data, 3) Integration of Cost, 4) Use of an Estimating Standard, and 5) Application of Automation or Augmentation. Additionally, from a definitional standpoint, using the five characteristics as a workflow litmus test will help the industry clarify expectations when engaging in MBE workflows, such as the Integrated Estimating workflow, or simply another ad-hoc based MBE workflows. Any solution, or workflow developed to support MBE workflows in a scalable and replicable manner should seek to support the five characteristics. In addition, each of the five characteristics is described in detail below, why each of them is important to overcoming adoption barriers, and how they contribute to the overall process. It is important to note the order of the characteristics as they are presented within the framework because they are both dependent on their predecessors and cumulative in their effects on the overall workflow.

Intentional Model Authoring

The *Intentional Model Authoring* characteristic requires that every object created in a model is authored with the knowledge and intent to be utilized in a downstream analysis function. In this case, the purpose is estimating. Intentionality is a model-authoring mindset that encourages a baseline for model quality, which is necessary to be in place to achieve the next characteristic successfully. An example of intentional model authoring is ensuring that the name of the model object created reflects the building elements they virtually represent. For example, in practice it is not uncommon to find a model object named, “slab on grade” being used to represent an elevated floor slab in a model, and this is because both the model authoring application does not prohibit this kind of incorrect action, and the model author is not focused on this aspect of the model as part of their task.

Qualitative and Quantitative Model Data

Qualitative and Quantitative Model Data characteristics are a requirement for model objects to be identifiable using metadata (metadata is data that provides information about other data), and measurable using dimensional parameters or other information associated with model objects.

The term “Qualitative” indicates that model objects must contain information that allows a consumer to intuitively identify an object in the model and interpret what the object virtually represents. The Integrated Estimating framework suggests that the minimum qualitative requirements include three specific types of metadata:

- Functional Component Breakdown – Also called, “Parent Object”, or “Location 1 Values”, these are high-level metadata properties that identify parent-child relationships between parts and pieces in a project and help to communicate parts of a project within larger projects with multiple buildings.
- Building System Category Values - These are any industry-accepted, standard classification systems that reflect where a given object exists in a building, or to which building system the object belongs. In some commercially available software applications, these are called Assembly Codes. Regardless, the classification strategy should rely on accepted industry standards, such as the CSI Uniformat Classification system which represents building systems.
- Model Object Name – This is the name given to an individual model component that enables the viewer to intuitively interpret what scope of work the model object represents simply by the description it is given. In some commercially available software applications, this is called the object “Type Name”.

The term “Quantitative” indicates that model objects are measurable and quantifiable based on the properties or parameters of the model object. These properties and parameters enable a user to count, measure, or quantify the object accurately. Quantifiable properties can be “first-class” dimensional properties, such as dimensions inherent to the object itself, or dimensional descriptions in the metadata associated with the object (e.g., steel member sizes).

Integrated Cost

The *Integrated Cost* characteristic requires that the workflow enables or facilitates a digital “link” between the model objects (the source of the quantity data) and the cost item/quantities in the estimating application system. This characteristic, which is where the framework gets its name, establishes a connection between the estimated cost item and the model itself. From a workflow qualifying standpoint, it explicitly prohibits the manual extraction of quantities from a model and the manual transfer and inputting of quantity values into the estimate.

This step is important for two main reasons. First, it eliminates the potential for human error in transposing quantity data from the model to the estimate. Secondly, it establishes a form of “digital integrity,” allowing any future user to trace the quantity used in the estimate back to the original source. In essence, this workflow step creates a digital “chain of custody” that reinforces the integrity of the estimating process. This step is also needed to support other characteristics, such as the application of automation to the process.

Estimating Standard

The *Estimating Standard* characteristic ensures that an estimating standard is being utilized to quantify the model objects. This is important because traditional forms of MBE often pursue an “ad hoc” quantification strategy, by necessity, due to the unpredictability of model quality or model completeness. The Integrated Estimating workflow seeks to prevent ad-hoc approaches to MBE in two ways.

- First, the framework provides a methodology to achieve consistency in the model authoring phase of the workflow using the first two characteristics. When adopted, this affords some level of predictability for when the model reaches the estimator.
- Secondly, the framework assigns terminology to practices many experienced estimators likely already practice but have not had the language to accompany and define their practices. Often, these practices are deployed in earlier design phases where design intent is looser and less defined. Therefore, codifying these practices enables them to be teachable, repeatable, and scalable. This is analogous to how McCuen (2015) identified the AACE uses of Stochastic and Deterministic methods to define quantity takeoff strategies at various stages of design.

Similarly, the Integrated Estimating framework introduces an estimating standard called, Model Quantity Origin, that supports flexibility in its application and, therefore can be deployed during early design phases when design concepts are less resolved, and design intent is intentionally loosely communicated. Model Quantity Origin offers three quantity takeoff or estimating approaches for the estimator depending on the LOD of a scope of work. This creates an “LOD Flexible” strategy to approach models for estimating. The approaches are Model-Based, Model-Informed, and Model-Inferred.

- Model-Based – Similar to the Deterministic method cited by McCuen (2015), this strategy links cost items directly to the “first-class” dimensional properties of model objects, because the model object is a virtual, but accurate, representation of the real-world object.
- Model-Informed – Similar to the Stochastic method cited by McCuen (2015), this strategy links cost items to model objects that are related to the scope of work being estimated but may not be an exact virtual representation of that scope of work and requires some interpretation of variables to derive a quantity. An example might be an exterior wall object where framing, sheathing and finish materials are not identified as individual model objects, but rather as one composite object.
- Model-Inferred – Similar to the Stochastic method, this strategy links cost items to model objects that may have no real relationship to the scope of work or building system being estimated, but quantity information can be reasonably inferred from the object to estimate a given scope of work.

Application of Automation or Augmentation

The *Application of Automation (or Augmentation)* characteristic requires that some form of automation or machine-based augmentation is deployed during the Integrated Estimating process. Automation is important because it enables the industry to improve productivity and efficiency over traditional, more manual processes. However, automation is typically unsuccessful when applied to processes that are not consistent, predictable, or scalable. Because of this, the fifth characteristic of the framework relies on, and therefore helps to ensure and reinforce the first four characteristics. Examples of automation and augmentation include change management features that seamlessly handle design and model updates, or the pre-linking/mapping of cost items from a cost database/library to a model object library or based on name recognition and other devices.

Results and Discussion

The proposed Integrated Estimating framework was deployed on over 60 projects from January 2020 to October 2023. These initial projects revealed preliminary success and indicated potential for future success if deployed at scale. To that end, the Integrated Estimating framework is an uncomplicated standard for model authors to follow and it does not impose significant burdens on the model author’s modeling activities. Secondly, the framework offers estimators a strategy for dealing with models that vary in LOD. This enables the model-based approach to be deployed earlier in the design phases when the design is not fully resolved or developed. Third, it codifies the digital link between the model object (source of quantity data) and the cost item as a prerequisite to achieve the workflow. As a result of these three findings, the proposed framework creates an environment that can subsequently address many of the most common and recently cited barriers to adoption, such as LOD standardization, lack of model quality standards, lack of estimating standards, and lack of a common classification system.

In these early project implementations, success was experienced in several areas:

i. The estimator’s comprehension of the design increased due to higher quality and a consistent model organization/structure.
ii. Use of the model was extended into earlier design phases. This was due to deploying a flexible LOD approach supporting the use of models in various design phases.
iii. Estimating labor was reduced by 30%-50% in several instances. This was attributed to having a simple structure for organizing the model objects which increased model comprehension, consistency, and usability, thereby reducing quantity takeoff durations.

iv. Change management features in the software expedited the design and model update process through automation because cost items were linked directly to model objects.
v. Conveyance of cost information to 3rd parties was also improved due to the ability to use the model to convey and communicate cost information and cost assumptions through the visualization capabilities of the model objects linked to cost items in the estimate.

These early indicators of success support and align with previous research of successful MBE workflows (Vigneault et al., 2019).

Additionally, while the framework is software agnostic, it invites commercial software products to participate in this next generation of preconstruction tools by identifying the features and functionality that will help support the teams who use this framework. These are features such as the ability to express the connection of cost items to model objects and quantities through a digital link in the application, as well as change management features that maintain connections to model geometry during model update processes, and the ability to automatically map cost items and cost assemblies from a cost catalog using manually pre-mapped associations or even the use of natural language models in artificial intelligence to seek out obvious connections.

Conclusion

This study identifies and proposes an uncomplicated but standardized framework for MBE that directly addresses common adoption challenges. The Integrated Estimating framework identifies five fundamental characteristics that distinguish it from other practices commonly referred to as MBE workflows and explains the Integrated Estimating framework's relevance to solving current adoption challenges. For clarity purposes, this study also recommends and establishes the use of the term, "Integrated Estimating" (when all five characteristics of the framework are utilized), as a more accurate term for industry adoption in lieu of "5D" or simply "model-based estimating". This use of this terminology will prevent confusion when MBE practices are solicited and clarify the methodology being utilized in practice.

Being early and having access to limited data sets, this study could not support more in-depth statistical analysis, or more in-depth case studies involving multiple users. Future research opportunities are significant and could include conducting more rigorous studies to validate the framework from other experts, as well as measuring productivity gains over traditional workflows. Other research could evaluate the enhanced collaboration that could come from design and preconstruction teams using the framework as a collaboration strategy. One final recommendation from this study is the opportunity afforded to academia and industry who choose to use the proposed workflow for teaching and training. This framework can be taught in a laboratory setting for academia to allow students to experience the benefits first-hand. For industry, the framework provides excellent upskilling opportunities for existing professionals.

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