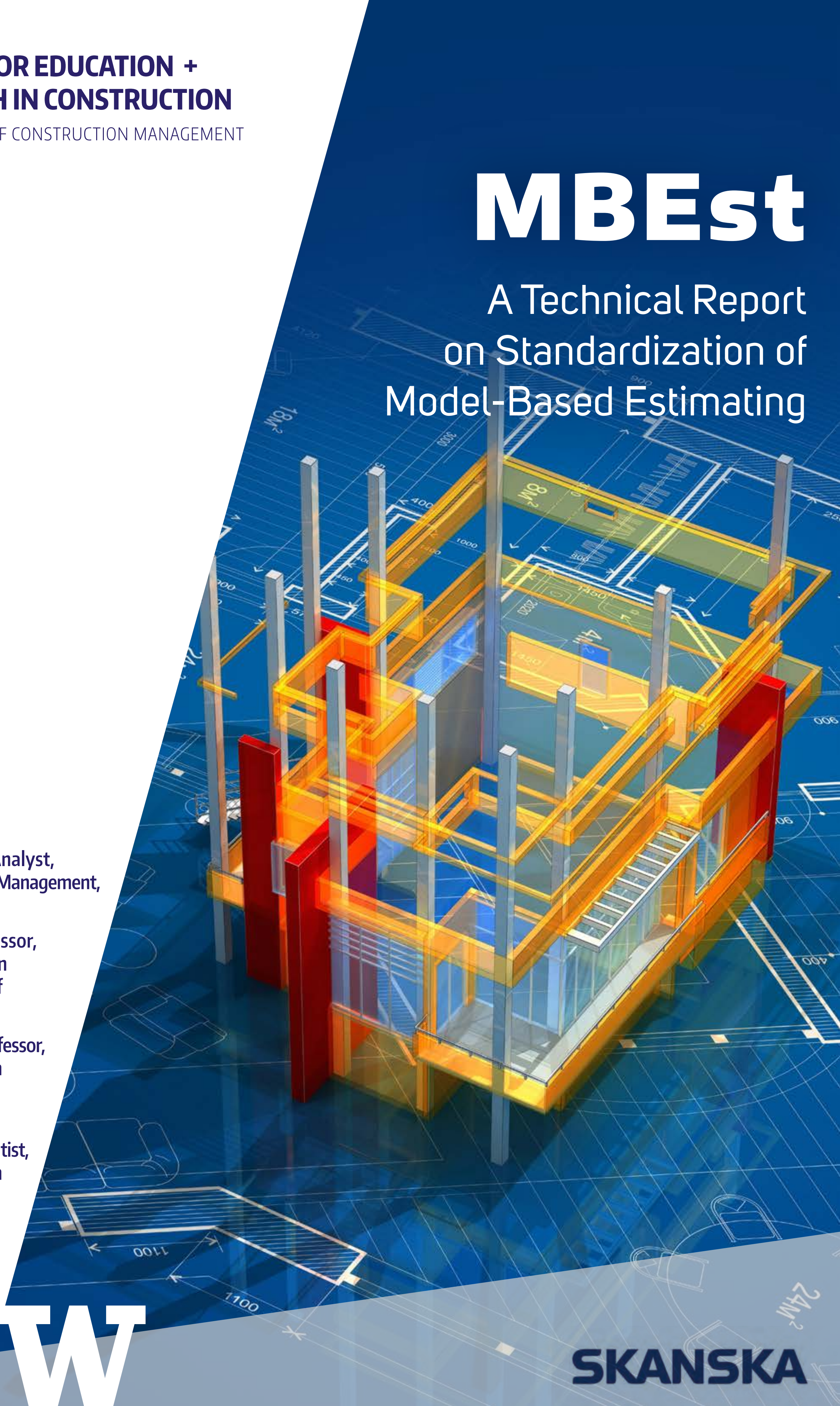
CENTER FOR EDUCATION + RESEARCH IN CONSTRUCTION
DEPARTMENT OF CONSTRUCTION MANAGEMENT

MBEst

A Technical Report on Standardization of Model-Based Estimating



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EXECUTIVE SUMMARY

Building Information Modeling (BIM) has triggered fundamental changes in processes and procedures of design, construction, and project management. In addition, BIM has led to new professional relationships between team members inside an organization and new contractual relationships between different organizations including owners, designers, and general contractors (GC). At this time, most of the large GCs have BIM/VDC departments in which BIM experts collaboratively work with other team members to develop and adopt new BIM uses. For instance, during the preconstruction phase, BIM experts along with other relevant staff (e.g., project engineers, managers, and estimators) form a preconstruction team to perform BIM-based constructability review, project planning, and cost estimating.

Project cost estimating is an important part of construction project management. Traditionally, estimators use project drawings and specifications to create quantity takeoffs (QTO) and subsequently calculate sub/total costs based on their judgments and historical cost information. In this method, estimators have to spend a majority of their time extracting quantities and dimensions from 2D drawings. Yet, results are sometimes inaccurate due to lack of time allocated for estimating or lack estimators understanding of design intent in the early stages. Additionally, the time-consuming nature of the traditional 2D QTO method often does not allow for estimators to allocate sufficient time for cost analysis and value engineering, which can increase the chance of cost overruns and change orders during construction when estimates are not well-defined.

During the past decade, BIM practitioners in academia and industry have aimed to leverage BIM capabilities for cost estimating to overcome the current challenges. The result is BIM-enabled methods for QTO and cost estimation also known as Model-Based Estimating (MBEst). However, the effectiveness of MBEst has been limited mainly due to a lack of standard MBEst workflows and a lack of integration between design development and cost estimating processes. In response, the intent of this technical report is to make a comprehensive review of model-based QTO/estimating and to provide a standard method for BIM experts to adopt and implement MBEst.

This technical report contains five sections. The first section is the current section for the executive summary. Section 2 provides an overview of MBEst, including a definition as well as a summary of opportunities and challenges of implementing MBEst. Section 3 presents a review of current industry and academia research and MBEst practices. Section 3 also introduces existing MBEst tools. Section 4 presents a standard process and procedure for implementing MBEst including a MBEst workflow, a model QA/QC overview guideline, criteria for selecting MBEst workflows and toolsets, and a collaboration framework. Finally, Section 5 explains the required strategies and skillsets for successful adoption and implementation of MBEst.

1 MODEL-BASED ESTIMATING (MBEST) OVERVIEW

Definition

In general, Model-Based Estimating (MBEst) is a systematic BIM-based methodology for utilizing BIM capabilities for a construction project's cost estimating during the preconstruction phase. Accordingly, the process of MBEst consists of the following main steps:

- Extracting QTO datasets including estimating-related information (e.g., dimensions, quantities, relevant parameters) from design documents.
- Manipulating the extracted QTO datasets (e.g., modifying data, re-organizing data, and adding cost information)
- Transferring the manipulated datasets into estimating software and completing cost estimation.

In addition to the main activities of the MBEst (QTO and cost estimation), BIM is used to facilitate other related activities such as cost planning, budget management, design alternatives analysis, and value engineering. This report uses the more general term, "5D BIM," to refer to these related activities and it uses the term model-based estimating for the specific tasks of QTO and cost estimation.

In practice, implementation of MBEst depends upon the specific tools and practices a preconstruction team selects to use. Currently, most preconstruction teams create a QTO schedule from a 3D model's geometries and information, use a 3rd party bridging tool for data manipulation (tools selection varies from simple datasheet templates in MS Excel to more sophisticated applications), and manually transfer the dataset into their estimating software.

Figure 1 depicts the current practice of MBEst with tools' examples. As shown in this figure, there is no direct link between design authoring and cost estimating tools.

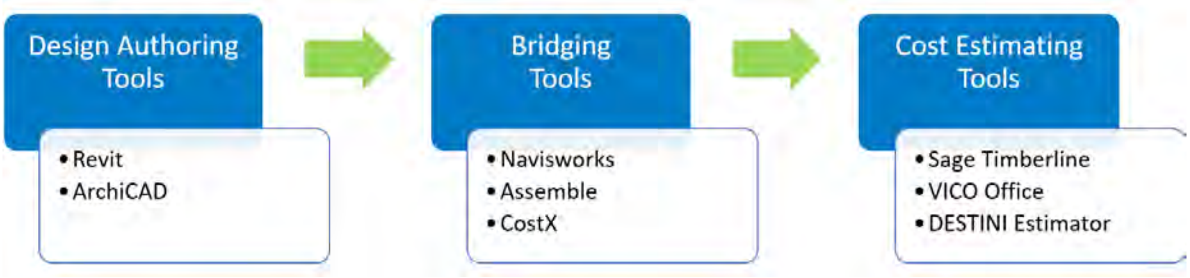

Figure 1. Current Practice of MBEst.

Ideally, a MBEst tool would be a cloud-based platform that provides a direct link between design authoring and cost estimating software, that allows for automated QTO dataset generation and organization, automated cost estimation through assigning cost information to proper items, and automated real-time response to design changes. Currently, there are a number of existing MBEst tools (e.g., CostX and Vico products) that provide QTO generation, data manipulation, and cost estimation features in a single tool. In spite of good progress made, there is still no perfect MBEst tool that is widely adopted by GCs and provides all required 5D BIM features.

Opportunities and Challenges

The main benefit of MBEst is to generate a QTO dataset in an automated, fast, and easy manner compared to traditional methods. In addition, proper implementation of MBEst provides preconstruction teams with the following opportunities:

- Accurate geometries' dimensions, areas, and quantities
- Less QTO time
- Better visualization of estimating
- Better understanding of design intent
- Rapid response to design changes and alternatives
- Tracking cost changes during design phases
- Time flexibility for preconstruction teams to focus on value engineering and cost control
- Early cost estimation to support decision-making
- Effective cost analysis and budget management
- In adopting and implementing MBEst, one has to overcome several technical and organizational challenges, including:
- Need of BIM model quality assurance (QA) and quality check (QC)
- Receiving no design model, especially during the early stages of design
- Low quality of design models
  - Incomplete models or duplicate objects
  - Incorrect/inaccurate information
  - Discrepancy between the model contents and drawings/specifications
- Unclear contractual agreements for delivering and updating BIM models
- Interoperability issues between different tools (specifically the manual process of transferring quantities into estimating software)
- Misalignment between current design development and cost estimating processes

Despite these challenges, MBEst is still a more efficient method for project cost estimating than 2D QTO. Furthermore, using the standard MBEst workflow and collaboration framework helps preconstruction teams take full advantage of the opportunities and mitigate possible challenges.

2 LITERATURE REVIEW: CURRENT MBEst PRACTICES AND TOOLS

MBEst Tools and Service Providers

To gain a better understanding of MBEst development, the CERC research team investigated current trends in academic research as well as proven practices and tools used by BIM practitioners in the industry.

MBEst tools are generally developed by (1) BIM software developers, such as Autodesk and Graphisoft and (2) BIM consultants and service providers that create either add-ins for the existing tools or develop standalone tools for various 5D BIM purposes. Table 1 introduces a number of MBEst tools that are relatively well-known in the United States. It should be mentioned that this table does not include tools with only estimating features or only 2D QTO features.

Table 1. Selected MBEst Tools.

Name	Product	Description
ACCA Software	PriMus-IFC	A platform for conducting QTO and estimating and creating quantities/cost reports from IFC files.
Assemble Systems	Assemble	A web-based platform for QTO, estimating, and design change management.
Autodesk	Revit	Autodesk's main authoring tool that contains basic features for quantity takeoff and estimation.
Autodesk	Navisworks	Autodesk's main QTO and estimating tool that supports both 2D and 3D documents (it has replaced Autodesk Quantity Takeoff).
Beck Technology	DESTINI Estimator	A Platform for estimating using 2D drawings and 3D models (Navisworks files) and generating reports in Excel.
Causeway Technologies	CATO	A platform for QTO from 2D/3D documents, estimating, cost planning, and cost management.
Dynamo	Dynamo	Although it is not a QTO/estimating tool, it can automate the repetitive process of creating objects and schedules inside Revit.
Exactal	CostX	A platform for QTO, estimating, and cost management that supports both 2D drawings and 3D models.
Ideate Software	BIMLink Explorer	Two Revit plugins used for BIM data management and exporting schedules into MS Excel.
Innovaya LLC	Visual quantity takeoff Visual estimating	Different products for quantity takeoff, estimation, and cost visualization.
RIB	iTWO	A platform for performing QTO, estimating, and cost planning based on BIM exported IFC files.
RubySketch	Plusspec	A plug-in for quantity takeoff inside Sketchup.
Sage	eTakeoff Bridge	A Navisworks' plugin for organizing/transferring data into Sage's estimating software.
Sigma Estimates	Sigma	A platform for organizing Revit information, conducting estimating, and generating various reports.
Solibri, Inc.	Solibri Model Checker	A platform for information takeoff from IFC files and generating quantities reports using customizable templates.
Vico Trimble	Vico Office	Different products for implementing 5D BIM.

There are currently a large number of MBEst tools available in the market. Therefore, identifying and evaluating each of these tools is a challenging task for preconstruction teams. A recommended method for comparing different tools is assessing the tools' general functionalities and their intended end users (e.g., BIM/VDC managers, designers, and estimators). For example:

- Tools with focus on QTO automation and design/QTO visualization used by designers and estimators.
- Tools with advanced data manipulation and data management usually used by VDC managers and estimators.
- Tools with various 5D capabilities including cost changes and budget management mostly used by owners and estimators.

Another method for comparing MBEst tools is focusing on their different dedicated features. The features of current tools include:

- Budget management
- Cost estimation/pricing
- Cost planning
- Data organization & management
- Design intent & cost visualization
- Model quality checking
- Quantity takeoff
- Relevant cost reports generation
- Rule-based data validation
- Track of design/cost changes
- Cost analysis & value engineering

In addition to the existing tools, BIM practitioners benefit from applying new technologies in the AEC (architecture, engineering, and construction) industry that expand MBEst opportunities. The following three technologies appear promising for integrating with MBEst:

- **Cloud-based platforms:** This technology allows every team member to have online access to BIM-based model and information produced by their colleagues without the need to use a specific tool. It also helps to share team data and to resolve the problem of sending/storing heavy BIM files. In addition, using a cloud-based platform enables team members to combine design models and cost information, which potentially leads to more real-time analysis of design and cost changes.

Figure 2. Using Cloud-based Platforms for Utilizing MBEst.[1]

- **Parametric & computational design:** This technology generally refers to using rules and parameters for automatically creating objects. Parametric design tools (e.g., Dynamo and Grasshopper) may be used for different MBEst purposes, such as generating design alternatives, rule-based model review/checking, and defining object classes for an automated QTO.

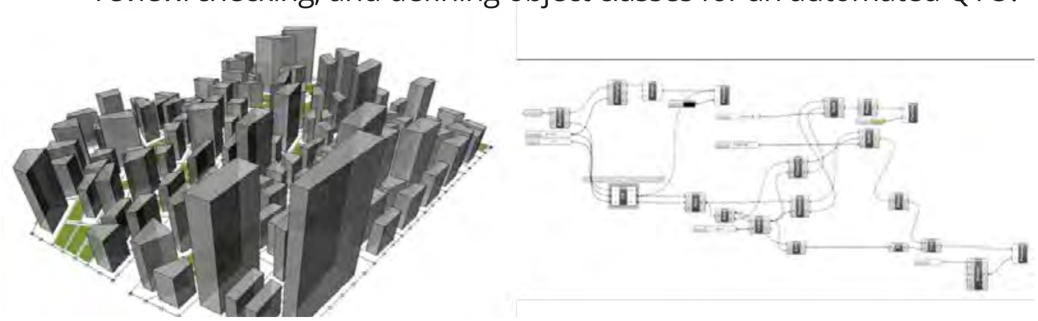

Figure 3. Using Dynamo for Parametric Design.[2]

1. Image source: Steve Jurvetson, CC BY, Content modified
2. Image source: trevor.patt, CC BY-NC-SA

- **Virtual Reality (VR)/Augmented Reality (AR) Technology:** VR/AR is a fast evolving and popular technology in the AEC industry. In the context of MBEst, one can leverage this technology mainly for innovative cost visualization and design alternatives analysis.

Figure 4. Using VR and Game Engines for Design Alternative Analysis.

Best Practices from Academia and Industry

Since the emergence of MBEst tools, both industry and academic sectors have provided numerous guidelines, best practices, and workflows to enhance the usability of commercial software tools. A summary of these efforts is presented in this section.

First, Table 2 shows a list of selected proven practices provided by BIM industry participants including BIM professionals, software developers, and service providers. These practices allow for more efficient use of the current MBEst tools.

Table 2. MBEst Proven Practices and Workflows.

Title / URL	Reference	Tools	Description
Advanced Techniques for Managing Building Data in Revit	Mario Guttman, Autodesk University	Revit MS Access	An overview of BIM data management and presents an Access-based product for Revit data extraction and organization.
Assemble Tutorials	Assemble Systems	Assemble	Tutorial videos for using Assemble in model quality checking, model conditioning, and estimating.
BIMLink Tutorials	Ideate Software	Revit BIMLink	Tutorial videos for using BIMLink in managing Revit export data and publishing schedules.
CostX Tutorials	Exactal	CostX	Tutorial videos for using CostX in quantity takeoff, estimating, and creating cost plans and reports.
Creating a Detailed Quantity Takeoff in Navisworks	Autodesk Education	Navisworks	A detailed tutorial on Navisworks' features for quantity takeoff.
DESTINI Estimator Tutorials	Beck Technology	DESTINI Estimator	Tutorial videos for using DESTINI Estimator for quantification and creating estimating reports.
Estimating with Navisworks Quantification	Kevin Miller, Autodesk University	Navisworks	A QTO workflow including a visual quality check, model preparation, assigning items to quantification workbook (either systematically or drag & drop the whole selection tree), and exporting schedule into Excel for data manipulation.
Model-Based Estimating with Revit	Gayane Aghazarian, Howard S. Wright	Revit	A workflow for quantity takeoff of interior walls. The workflow includes model verification (creating filters), model repair, creating wall schedules, adding cost information, and presenting the estimate.
No Estimation Without Quantification: Assemble Your Quantities Today	Kris Lengieza, Autodesk University	Revit Assemble	An overview of quantity takeoff including assembling team and having a quantification plan. It also provides a workflow for leveraging shared parameters, quantities visualization, and change management.
Proper Use of Navisworks for Quantification	CAD Technology Center	Revit Navisworks	A QTO workflow consisting of preparing a model in Revit, setting up Navisworks' quantification workbook (using a customized template vs. standard costbooks), and adding items into catalogs.
Sage Estimating eTakeoff Bridge	Sage	eTakeoff Navisworks	A solution for QTO from 2D/3D documents that transfer them into Sage estimate. The workflow includes model review, assigning objects to the Navisworks' catalog, modifying attributes, and transferring quantities for estimating.
Solibri Tutorials	Solibri Inc.	Solibri Model Checker	Tutorial videos for using Solibri Model Checker in both quality checking and information takeoff.
Takeoff to the Next Level with Navisworks 2D and 3D Quantification	Jason Dodds, Autodesk University	Navisworks	A tutorial on quantification process and Navisworks quantification features. Topics includes setting up items/resource catalogs, customizing formulas, and proper use of model/virtual/2D takeoffs.

In addition to the practical workflows and proven practices, academic researchers have also studied different aspects of utilizing BIM for cost estimating and have presented innovative solutions for the current MBEst challenges. Table 3 provides a categorization for current trends in recently published MBEst-related research and literature.

Table 3. Recent Trends on Academic Research with Examples from the Literature.

Research Trend	Description/Reference
Overview of model-based QTO and cost estimation processes and procedures	• Adoption and implementation of 5D BIM (Sattineni et al. 2014) • A general investigation of QTO and estimating (Eastman et al. 2011) • Developing a knowledge-based framework for QTO/estimation (Aram et al. 2014) • Investigation of functions/requirements of a BIM-based estimating software (Ma et al. 2010) • Overview of estimating process and tools (Wu et al. 2014) • Developing a workflow for 5D BIM (Forgues et al. 2012) • A review on integration of BIM and cost management (Sunil et al. 2015) • A holistic review of using BIM for cost estimating (McCuen 2015)
Solutions for improving automation/accuracy of QTO generation using existing tools	• Algorithms for extracting geometries dimensions (Han et al. 2017) • Investigation of ArchiCAD's QTO features and requirements (Monteiro et al. 2013)
Using open BIM standards for automated QTO	• An IFC-based method for automated QTO (Mandava et al. 2016) • IFC-based mechanism for generating bill of quantities (Ma et al. 2011) • An Open BIM-based method and QTO process for schematic estimation (Choi et al. 2015)
New methods for model quality control and improvement	• Developing a framework for BIM-based model checking (Hjelseth 2016) • Automated model improvement for QTO (Kim et al 2009) • A classification of automated rule checking systems (Solihin et al. 2015)
Innovative methods for automation of cost estimation activities	• An ontology-based method to consider design conditions for cost estimation (Staub-French et al. 2002) • Developing an estimating's rational information system for automated cost estimation (Xu et al. 2013) • Adopting an approach for automated mapping between BIM objects and cost information (Lawrence et al. 2014) • An ontology-based approach for assigning cost information to work items (Lee et al. 2014)

In general, academic literature offers innovative solutions for the technical issues of existing MBEst tools. However, the feasibility and validity of some solutions require further verification in real-world conditions. Moreover, some studies do not consider the organizational barriers for adopting their suggested solutions. It is concluded that a strong partnership between academia and industry will benefit both parties and lead to more tangible improvements in current MBEst tools and practices.

3 MBEst IMPLEMENTATION PROCESS & PROCEDURE

Adopting and implementing MBEst requires Inevitable organizational changes in professional relationships between team members (e.g., BIM experts, estimators, and managers) and technical changes in current design, estimation, and management approaches. Moreover, it necessitates inter-organizational changes in contractual relationships between owners, designers, and contractors. As a result, project stakeholders should work together collaboratively to determine and coordinate the processes, tools, and standards that they use for implementing MBEst. To facilitate this collaboration, this technical report provides a standard MBEst workflow, a guideline for model QA/QC, criteria for selecting MBEst workflows/toolsets, and a framework for collaboration between project stakeholders.

Developing Standard Workflow

The developed MBEst workflow is a standard roadmap for preconstruction teams while using BIM tools for QTO and cost estimation during different phases of design. The MBEst workflow consists of three main components including:

- **Process:** the required main steps of the MBEst workflow.
- **Activities:** the required tasks that a preconstruction team should perform at each step.
- **Tools:** software applications used to accomplish the required activities.

To create a balance between standardization and customization, preconstruction teams should follow a standard process while customizing activities and tools based on their project's requirements.

Steps of the Workflow

The main steps of the MBEst workflow are shown in Figure 5. In this figure, three groups of boxes (distinguished with different shapes and colors) represent the workflow's process (bottom), activities (middle), and potential tools (top).

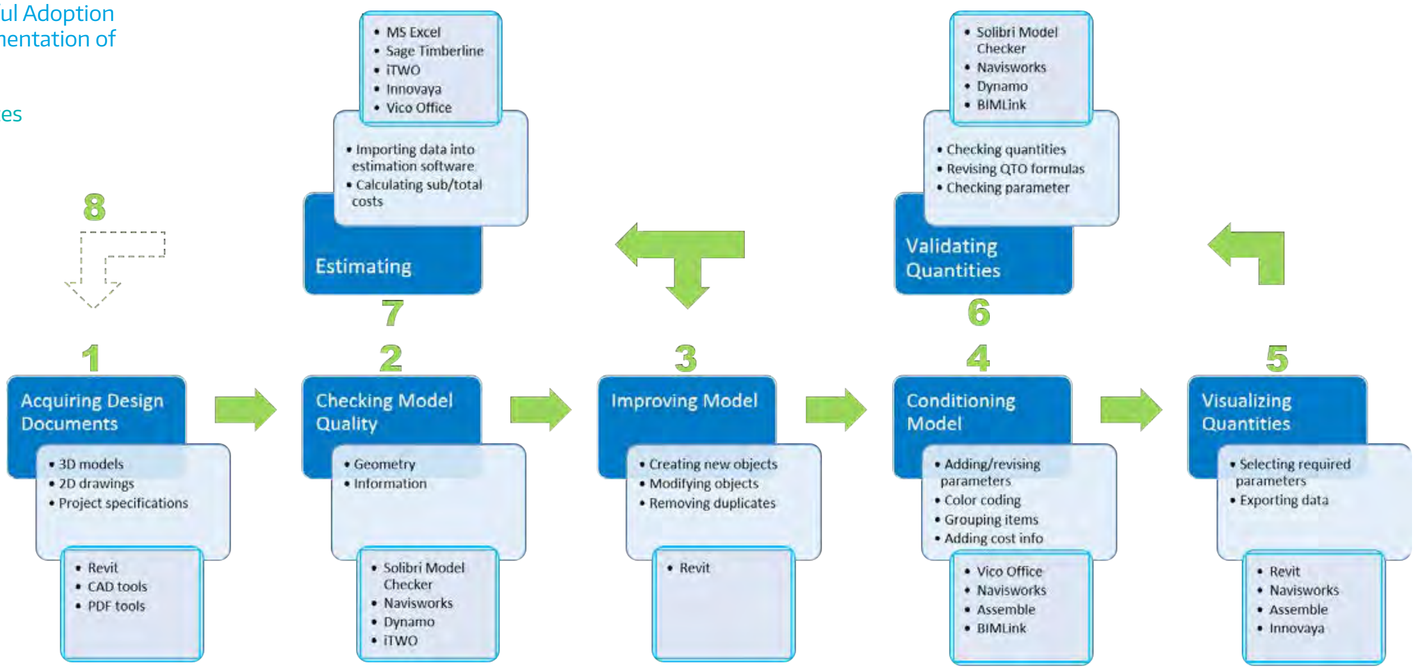

Figure 5. MBEst Standard Workflow.

The MBEst workflow contains eight steps:

1. Acquiring design documents: The preconstruction team may acquire needed MBEst information from different sources including 3D model, 2D drawings, narratives, or project specifications and visualizations depending on project types, design partners, design phases, and building trades. If preconstruction teams do not receive a proper design model from architects (especially in the early design stages), they may consider creating a 3D model in-house.

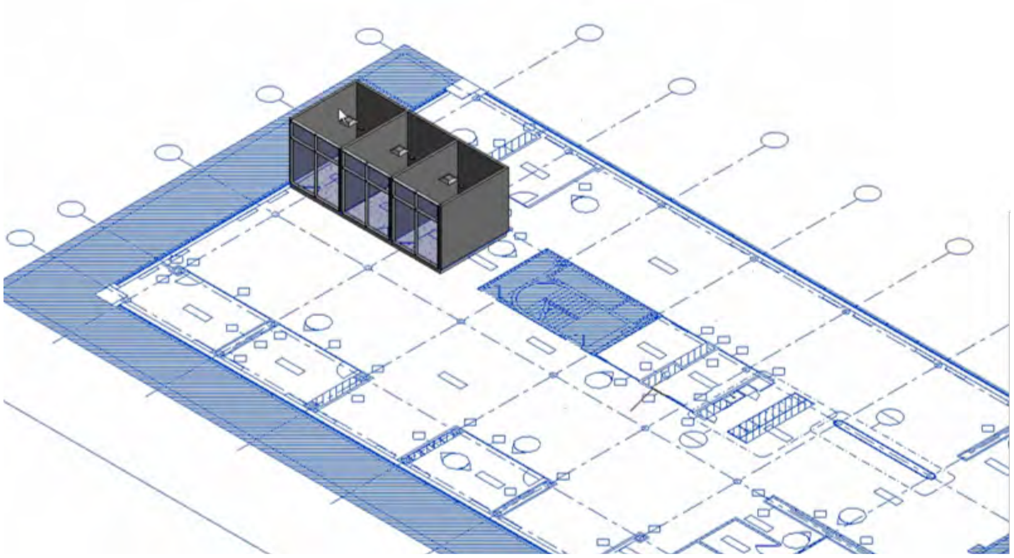

Figure 6. Using 2D and 3D documents for MBEst.

2. Checking model quality: The preconstruction team evaluates the quality of a received model in terms of its geometry and information based on pre-established QA requirements to determine what parts of the model are usable for MBEst. Based on the results of model QC, model improvement and conditioning might be required. The preconstruction team should decide between modifying the model in-house and communicating quality issues to designers. To do this, the preconstruction team needs to consider time constraints, in-house BIM skills, types of quality issues, and the designer's contractual agreements.

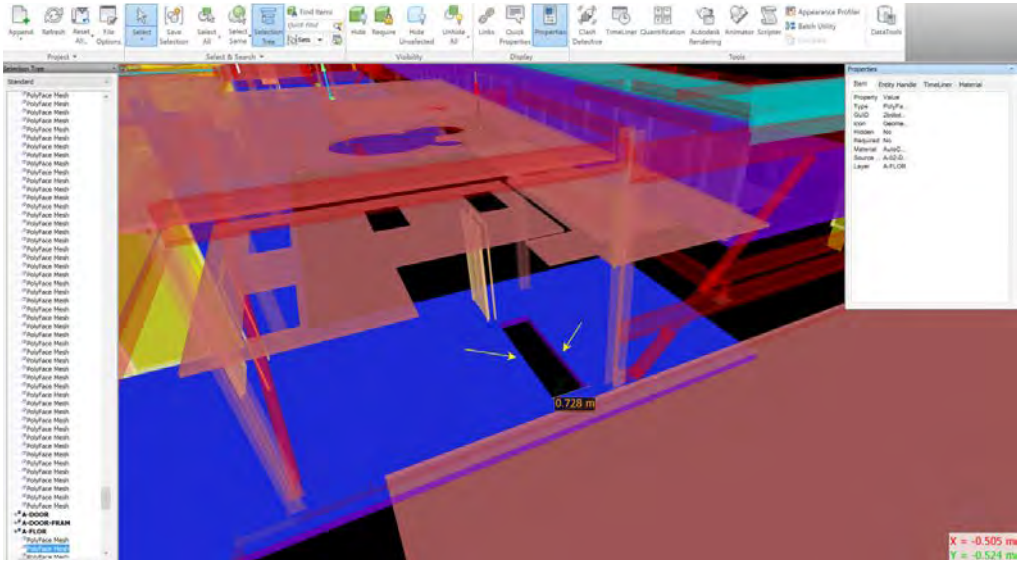

Figure 7. Conducting Model QC.

3. Improving the model: Based on the results of model QC, the preconstruction team may need to add new objects, modify existing objects (e.g., splitting a column based on floor levels), and remove duplicate objects.

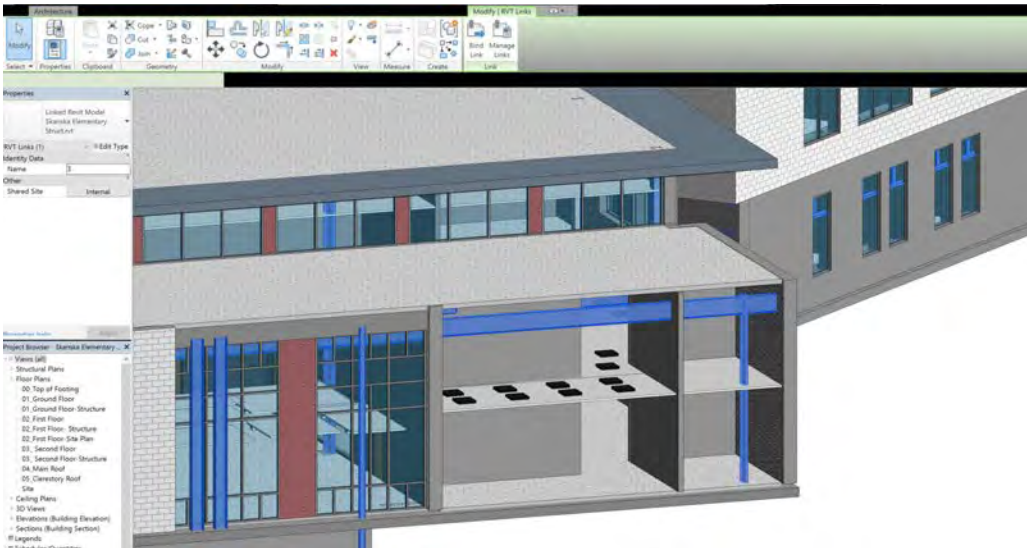

Figure 8. Improving Geometries Inside a Model.

4. Conditioning the model: In this step, the preconstruction team makes a systematic visual review of information assigned to objects and performs required revisions including adding, modifying, and removing parameters; color coding (based on cost codes or building trades); re-grouping and organizing items based on classification systems or estimators' customized formats; and adding cost information.

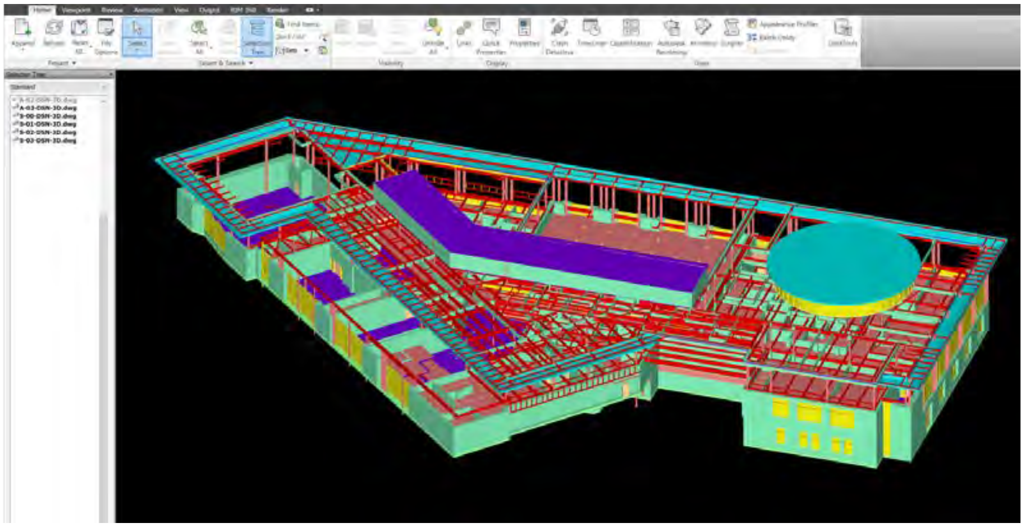

Figure 9. Performing Color Coding.

5. Visualizing quantities: This step involves selecting essential families & types and parameters (in coordination with estimators) and creating/visualizing QTO schedules for intended building trades.

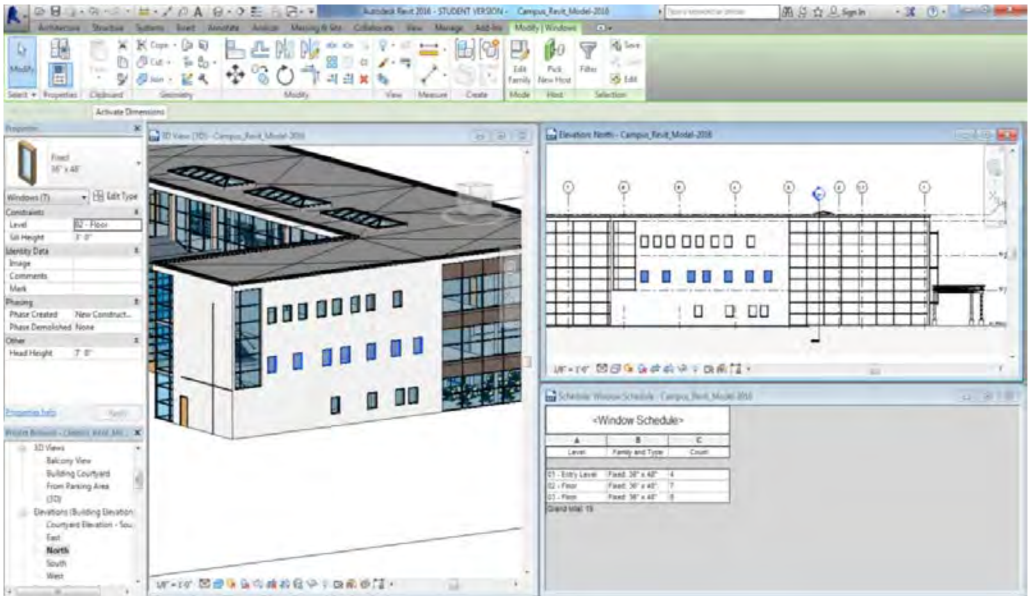

Figure 10. Creating and Visualizing QTO schedules.

6. Validating quantities: This step involves ensuring the existence and accuracy of the extracted quantities, checking calculation formulas and making needed revisions (e.g., using custom area calculation formulas to address wall/ceiling openings), and checking the completeness and accuracy of required parameters. Based on the results of quantity validation, further model improvement and conditioning may be required.

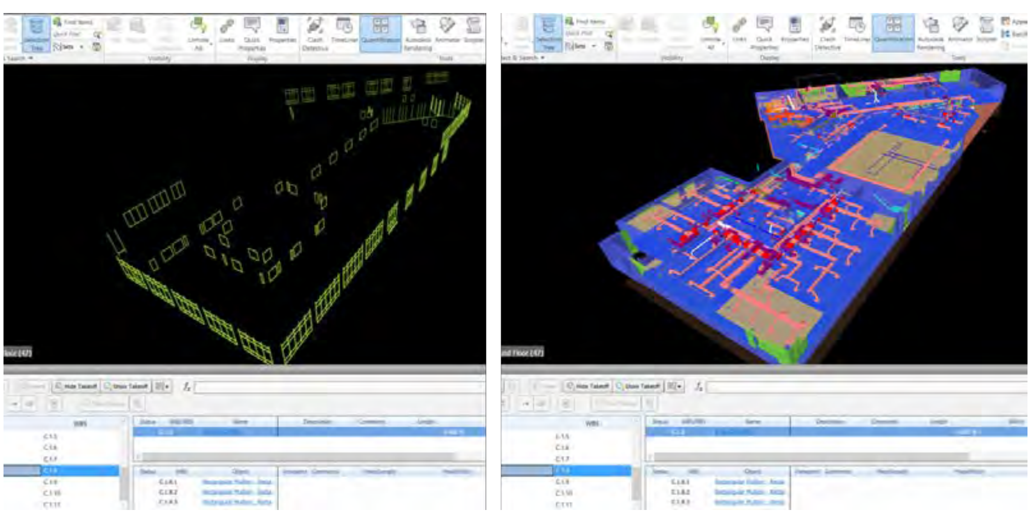

Figure 11. Conducting Model Validation.

7. Estimating: The preconstruction team transfers the prepared QTO schedule into an estimating software program (if needed) and assigns cost information (e.g., unit costs, resources information, and bid packages information) to the quantities to calculate sub and total costs.

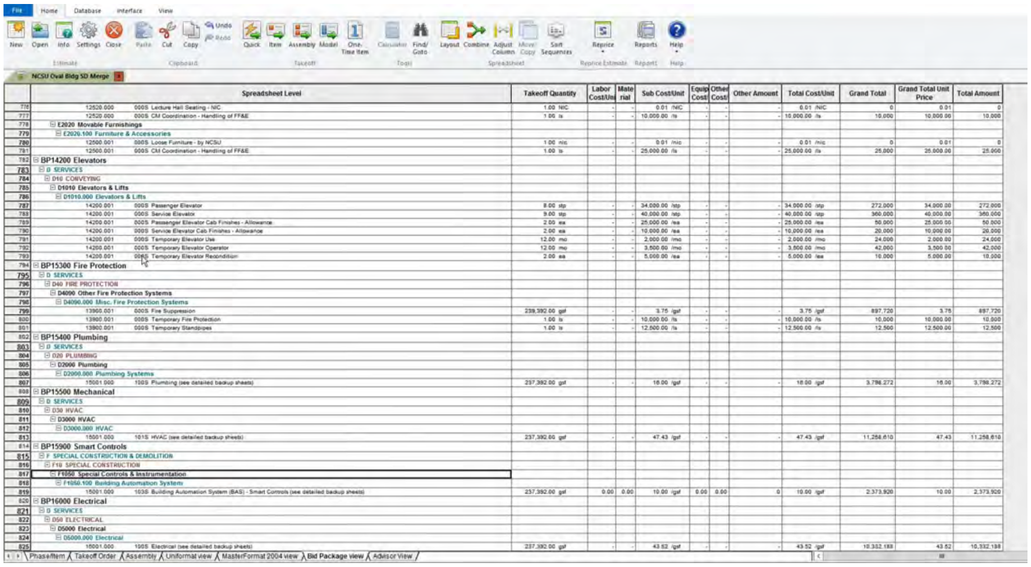

Figure 12. Completing Cost Estimating inside an Estimating Software.

8. Updating the design model: Since the MBEst workflow is an iterative process conducted during different design phases, the preconstruction team should sync information to the central design model (if possible) to repeat the process with updated model content as the design matures.

To execute the MBEst workflow, it is recommended that a BIM expert begins the process and conducts model QC and needed model improvements and conditioning. Next, the BIM expert should create QTO schedules in cooperation with estimators and share the dataset with other team members for validation and verification. Subsequently, estimators continue the process by completing cost estimation and other 5D BIM related activities, if needed.

Workflows Selection Criteria

In practice, the MBEst workflow can be implemented in varying ways, because preconstruction teams use various methods and tools to perform MBEst activities. Figure 13 explains criteria that impact the MBEst workflow as well as indicators for a quantitative understanding and measurement of each criterion. It is recommended that managers consider these criteria during the early project's kickoff meetings to help the preconstruction team adjust the MBEst workflow based on their unique project requirements.

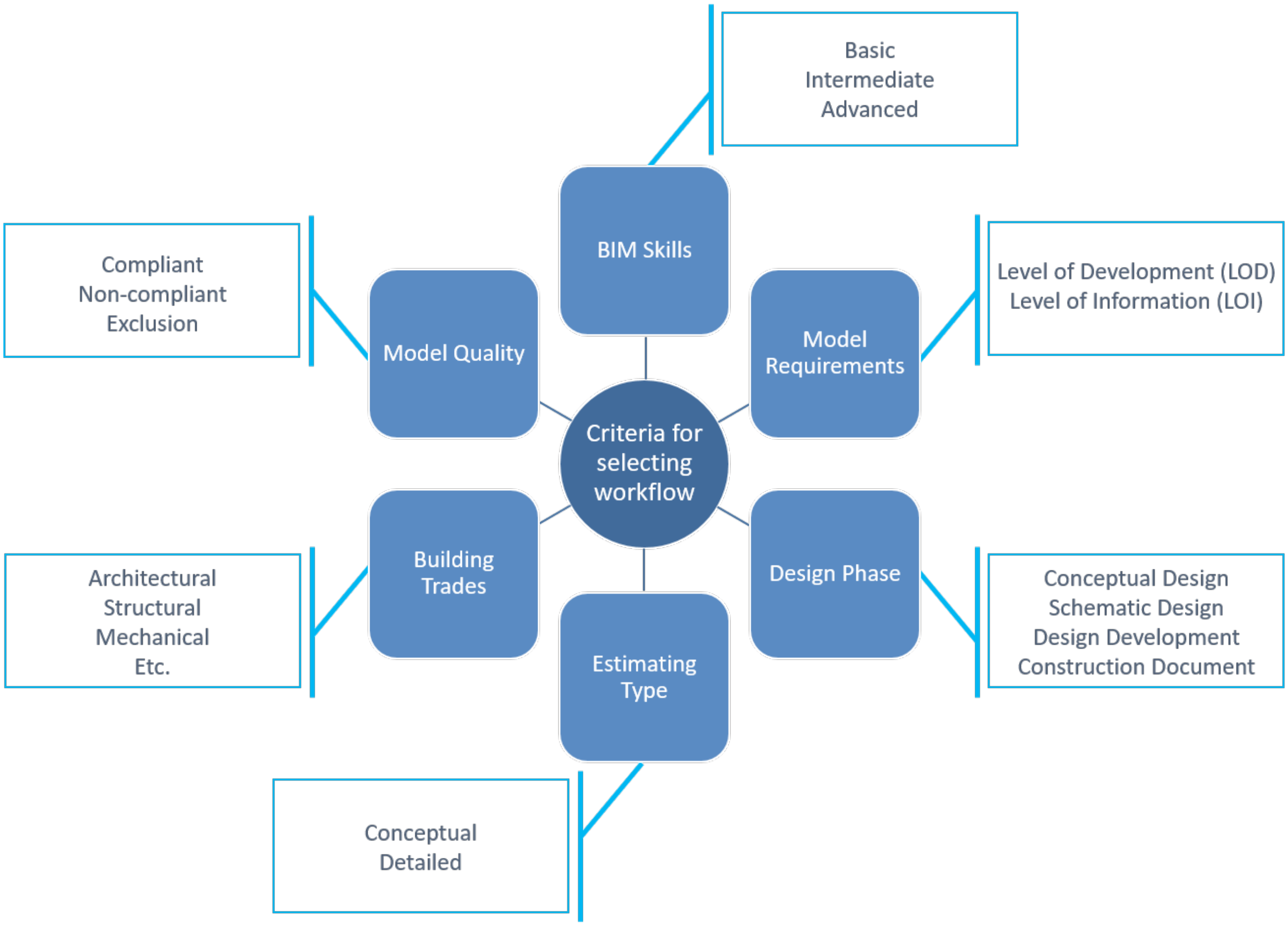

Figure 13. Criteria for Selecting MBEst Workflows.

Below is a brief definition of each criterion:

- **BIM Skills:** Level of a preconstruction team's BIM skillsets for implementing the MBEst workflow (evaluated by basic, intermediate, and advanced degrees).
- **Model Requirements:** The BIM model's geometries and information requirements for each building trade during different design phases (determined by LOD/LOI levels).
- **Design Phase:** The stage in the design process (e.g., conceptual design, schematic design, etc.) when MBE will occur.
- **Estimation Type:** The different methods of estimation used during different design phases (categorized as conceptual and detailed estimates).
- **Building Trades:** The different building systems (e.g., architectural, structural, mechanical, etc.) created in a BIM model.
- **Model Quality:** The level of information accuracy and completeness of the modeled objects (reported as compliant, non-compliant, and exclusion).

Conducting Model QA/QC

Model Quality Overview Guideline

An important step of the MBEst workflow is model quality checking (QC). The process of model QC can potentially become time-consuming and error-prone depending on the quality of the design model, contractor-designer collaboration, and tools used for QC. To facilitate this process, preconstruction teams should communicate their estimating requirements to design teams during the early stages of design. For this purpose, a preconstruction team develops a model quality overview guideline to determine minimum requirements of geometries and information needed for utilizing MBEst. The guideline contains two parts: quality assurance (QA) to determine the requirements and QC to verify the compliance with the determined requirements.

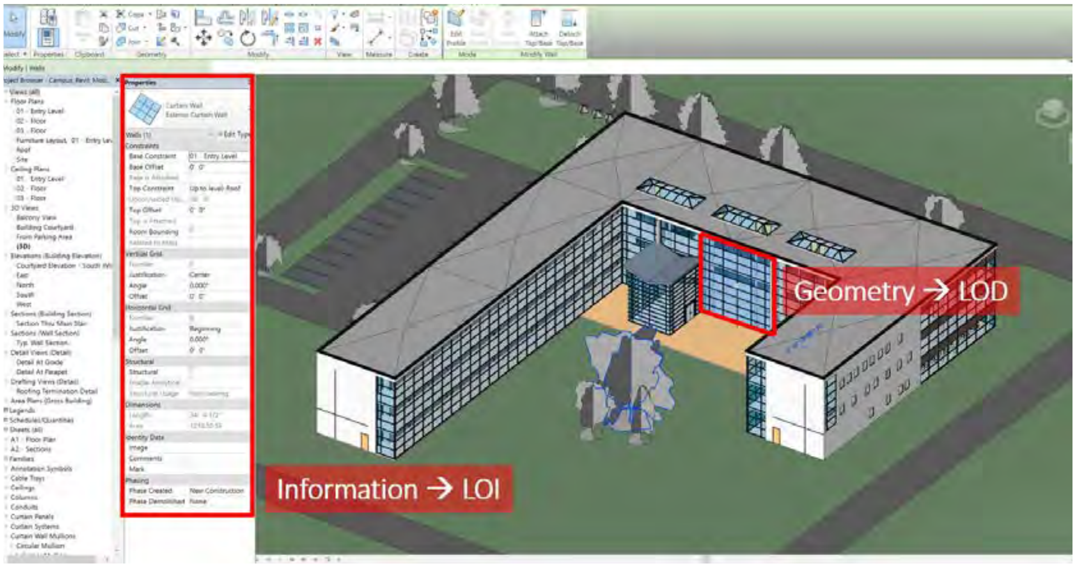

Figure 14. Geometry & Information Requirements Determined by LOD & LOI.

Geometries requirements are addressed through assigning the proper level of development (LOD) to different components of each building trade. For this purpose, the preconstruction team can define its own LOD system or use standard LOD specifications systems (e.g., document published by the BIMForum). Also, information requirements are determined by identifying parameters and formats that should be assigned to different geometries. It is recommended that the preconstruction team should define different LOI (Level of Information) levels (similar to the LOD system) for better categorization of required parameters. Figure 15 shows the structure of the model QA part of the guideline.

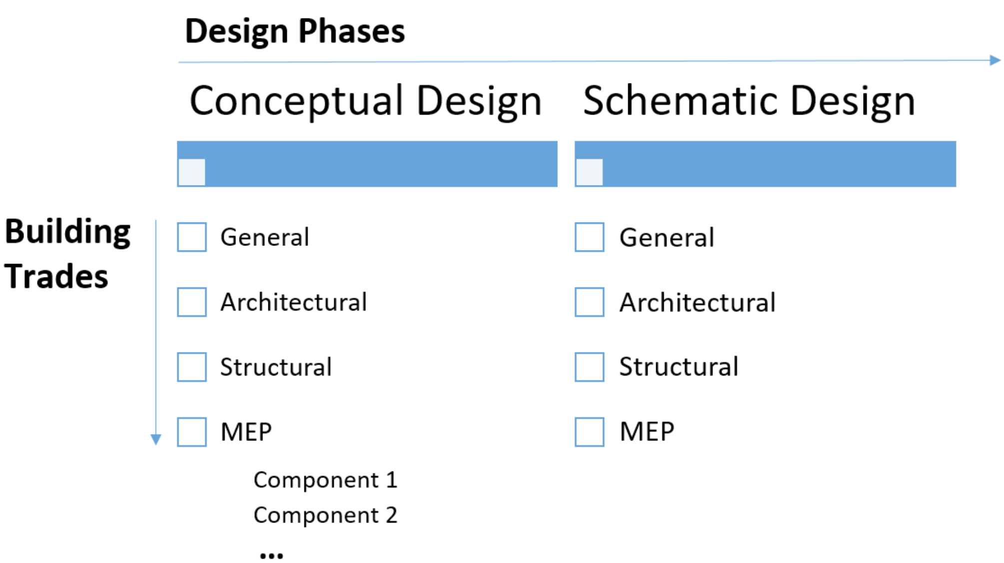

Figure 15. Structure of Model QA.

According to Figure 15, the structure of model QA depends on design phases and then building trades. In this regard, the preconstruction team should also determine the classification systems (e.g., UniFormat, Assembly Code) used for organizing building trades and relevant components.

1			Concept	SD				DD				50% CD				100% CD			
2	MODEL ELEMENT BREAKDOWN (CSI Uniformat)	Revit Category	In Model?	LOD	LOI	Resp	In Model?	LOD	LOI	Resp	In Model?	LOD	LOI	Resp	In Model?	LOD	LOI	Resp	In Model?
3	A SUBSTRUCTURE																		
4	A10 Foundations																		
5	Foundations, Piles & Grade beams	Structural Foundations	N/A	100	100	A/S	Yes	200	200	S	Yes	300	300	S	Yes	300	300	S	Yes
6	Slab on Grade	Floors	Yes	100	100	A/S	Yes	200	200	S	Yes	300	300	S	Yes	300	300	S	Yes
7	Perimeter/Under slab Drainage		N/A	100	100	A/S	N/A	200	200	S	N/A	300	300	S	Yes	300	300	S	Yes
8	Pits	Walls (exterior)	N/A	100	100	A/S	N/A	200	200	S	N/A	300	300	S	Yes	300	300	S	Yes
9	Underground Water Tanks		N/A	100	100	A/S	N/A	200	200	S	N/A	300	300	S	N/A	300	300	S	Yes
10	Insulation/Moisture Protection (Slabs)		N/A	100	100	A/S	N/A	200	200	S	N/A	300	300	S	N/A	300	300	S	N/A
11	Insulation/Moisture Protection (walls)		N/A	100	100	A/S	N/A	200	200	S	N/A	300	300	S	N/A	300	300	S	N/A
12	A20 Basement Const.																		
13	Basement Walls	Walls (exterior)	Yes	100	100	A/S	Yes	200	200	S	Yes	300	300	S	Yes	300	300	S	Yes
14	Veneer on Basement Walls	Walls (exterior)	N/A	100	100	A/S	N/A	200	200	S	Yes	300	300	S	Yes	300	300	S	Yes
15	Insulation/Moisture Protection		N/A	100	100	A/S	N/A	200	200	S	N/A	300	300	S	N/A	300	300	S	N/A
16	Interior Finish	Rooms (Indirect - Finish Schedule)	N/A	100	100	A/S	N/A	200	200	S	Yes	300	300	S	Yes	300	300	S	Yes
17	B SHELL																		
18	B10 Superstructure																		
19	Floor & Roof Construction	Structural Framing & Structural Columns	Yes	100	100	A/S	Yes	200	200	S	Yes	300	300	S	Yes	300	300	S	Yes
20	Floor & Roof Decks/Slabs & Ramps	Floors	Yes	100	100	A/S	Yes	200	200	S	Yes	300	300	S	Yes	300	300	S	Yes
21	Ramps	Ramps, Floors	N/A	100	100	A/S	Yes	200	200	S	Yes	300	300	S	Yes	300	300	S	Yes
22	Canopy Construction	Structural Framing, Floors or Generic Model	N/A	100	100	A/S	N/A	200	200	S	Yes	300	300	S	Yes	300	300	S	Yes
23	Dunnage and Grating	Structural Framing	N/A	100	100	A/S	N/A	200	200	S	N/A	300	300	S	Yes	300	300	S	Yes
24	Misc. Metals	Structural Framing	N/A	100	100	A/S	N/A	200	200	S	N/A	300	300	S	N/A	300	300	S	Yes
25	Gusset Plates	Structural Framing	N/A	100	100	A/S	N/A	200	200	S	N/A	300	300	S	N/A	300	300	S	Yes
26	Bracing	Structural Framing	N/A	100	100	A/S	N/A	200	200	S	N/A	300	300	S	Yes	300	300	S	Yes
27	House keeping pads	Floors	N/A	100	100	A/S	N/A	200	200	S	N/A	300	300	S	Yes	300	300	S	Yes
28	Raised Floor System	Floors or Generic Model	N/A	100	100	A/S	N/A	200	200	S	Yes	300	300	S	Yes	300	300	S	Yes

Figure 16. An Example of Using LOD/LOI in a Model QA Document.

Another part of the guideline is the model QC that includes a standard check-sheet for verifying the quality of a design model against pre-determined requirements once the model is received from design teams. The QC check-sheet includes QC criteria that address geometries and information requirements. There are generally two types of QC criteria:

- **General criteria** (e.g., model acquisition information, worksets, layout information)
- **Building trades/components specific criteria** (e.g., accurate/correct families & type labeling, redundant type name, relevant parameters assigned)

Quality checking results are reported by selecting either "compliant" (if the requirement is met), "non-compliant" (if there is an error in modeled geometry or assigned information), and "exclusion" (if the geometry doesn't exist in the model). The QC checksheet also serves as a basis for employing quality checking special tools.

Model QC tools

Preconstruction teams may use different methods to conduct a model QC:

- Perform a model walkthrough and visual inspection.
- Use a QC tool that is capable of running automated QC tests.
- Conduct a systematic review of QTO schedules.

The main benefit of using a QC special tool is to automate the process of quality checking (by means of pre-established rule sets defined based on a user's specific requirements) and to fix parameter-related issues. Table 4 introduces several model QC tools.

Table 4. The Selected Model QC Special Tools.

Name	Product	Description
dRofus Inc.	dRofus	A data planning and management platform. In the context of MBEst, it can be used for organizing extracted a QTO dataset and overwriting missing and incorrect data points.
Dynamo	Dynamo	A plugin that allows for defining rule sets for quality checking objects and parameters inside a Revit model.
iConstruct	iConstruct	This Navisworks' plugin provides features to facilitate clash detection, items management, parameters/tags revisions, and tracks design changes.
RIB Software	iTWO	This tool conducts quality checking through clash detection and applying rule sets for parameters' checking.
Solibri, Inc.	Solibri Model Checker	A platform for checking design issues based on pre-established customizable rule sets using BIM exported IFC files.

The proper development and use of the model quality overview guideline and QC tools provide the following benefits to preconstruction teams:

- Evaluates design model effectiveness for QTO and estimation.
- Identifies required model improvements and model conditioning.
- Increase in reliability of quantities to share with estimators.
- Sets up QC tools for automated quality checking.
- Reduces RFIs and design confirmation time.
- Creates more trust between design and preconstruction team members.

Exploring Toolsets

The MBEst workflow provides preconstruction teams flexibility for selecting an appropriate toolset to implement MBEst. However, finding a proper MBEst tool is a challenging task as it depends on a number of different factors including project requirements, preconstruction teams' goals and BIM skills, required 5D BIM features, and the workflow's customized activities. In addition, preconstruction teams should consider the following technical characteristics when selecting a MBEst tool:

- Model sharing possibilities (e.g., cloud-based platform, model viewer version)
- Interoperability options (supported input/output file formats)
- Model visualization features
- QTO schedules' customization capabilities
- Dedicated templates option for process automation
- Accuracy of calculated quantities

Another important factor for selecting a MBEst tool is whether it supports both 2D and 3D documents for the purpose of QTO. Although the MBEst workflow is mainly for QTO and cost estimation based on a BIM 3D model, the preconstruction team may choose to perform QTO from 2D drawings in specific cases. As Figure 17 suggests, using 2D takeoff for specific building trades, usually during the early phases of design, is considered a hybrid solution. The preconstruction team needs to decide when to use this option based on the results of their BIM model QC along with comparing the time needed for model improving/conditioning, data validating, and estimating (3D takeoff) and the time needed for reviewing drawings, counts/dimensions takeoff, and estimating (2D takeoff).

2D + 3D = 5D BIM

Figure 17. Using 2D and 3D QTO as a hybrid solution.

Preconstruction teams may use a single MBEst tool or a combination of tools based on the above-mentioned factors. Some software developers (e.g., Vico Trimble, Innovaya, and Beck Technology) offer software packages with special tools for different purposes. Furthermore, they may establish a partnership with other companies to provide improved integration and a direct link between their tools (e.g., Assemble & Procore and Navisworks & Sage Timberline).

Establishing Collaboration Framework

Goals and Objectives

Adoption and implementation of MBEst is not possible without a solid relationship and partnership between the project's key members: the design team and the preconstruction team. Therefore, the primary goal of the MBEst collaboration framework is to show to all stakeholders the value of partnership for implementing MBEst and to determine the rules for establishing an effective collaboration between design and preconstruction teams. Applying this collaboration framework can help create better value for clients through a proactive design and estimation process to:

- Leverage design models for estimating, decision-making, and effective communication at design and budget presentations; and
- Align design and estimating workflow processes and efforts.

Value Proposition

The collaboration framework improves values delivered to owners, contractors, and designers, including but not limited to:

- Support of MBEst to create more reliable and consistent quantities.
- Transparency of design and cost for all stakeholders leading to less RFIs.
- More value to owners because of better control of design, cost, and schedule.
- Less value engineering and re-design in later design phases.
- Contractor buy-in and support of design intent.
- Facilitate design team involvement and understanding of cost estimating process.
- Support for design alternative analysis (e.g., system selection).
- Effective and clear communication between design and preconstruction teams.

Roles & Responsibilities

Design and preconstruction teams should agree to take responsibility for providing the required materials and information within an accepted timeline.

In this regard, the design team (as model author) is responsible to define:

- The most important design intent elements and concepts.
- Design development processes and standards.

The preconstruction team (as model-based estimator) is responsible to define:

- Cost estimating processes and the most important cost drivers.
- MBEst model requirements (determined through the model QA).

Integration of Design Development and Cost Estimating Processes

In general, design teams have their own design authoring process and standards for developing design intent during design phases. Preconstruction teams also have their own process and procedures for cost estimating, which commonly causes a misalignment between design development and cost estimating processes when teams adopt MBEst. The collaboration framework aims to address this misalignment through increasing the design and preconstruction teams' understanding of each other's main activities and requirements.

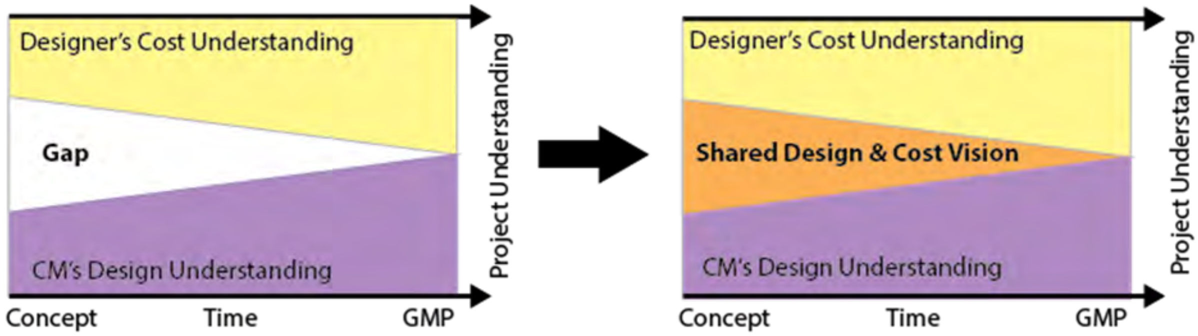

Figure 18. Addressing the Misalignment between Design Development and Cost Estimating.

In particular, a goal of the collaboration framework is to help preconstruction and design teams to develop a shared vision and shared understanding of design intent, project scopes, assumptions, and cost estimates throughout design development.

Moreover, the collaboration framework aims to integrate design and estimating processes so that one supports the other. For this purpose, design and preconstruction teams should work collaboratively to complete the following essential tasks:

- Create a joint BIM execution planning (BIM PxP) that contains information of all selected MBEst tools, protocols for data sharing and its platforms, key milestones and timelines of design development and bid package preparation, and information of key project team members who will manage implementation of the MBEst workflow.
- Schedule a series of meetings between design and preconstruction teams once a design model is shared or a major design update has occurred. The purpose of these meetings is to conduct model QC based on predetermined model requirements and to facilitate the process of creating and confirming shared design and cost understanding.
- Incorporate design and estimating processes into the standard MBEst workflow. To do this, both teams should review their internal processes and timelines including bid preparation milestones, budget review workshops, value engineering proposals, and design charrettes.

4 SUCCESSFUL ADOPTION & IMPLEMENTATION OF MBEst

Team Building and Partnership

A successful adoption and implementation of MBEst requires support and cooperation at organizational and inter-organizational levels. A pre-requisite to achieve this cooperation is establishing a partnership during the early stages of design. As shown in Figure 19, during the early design phases, the ability to impact cost is at the highest level while the cost of design changes is at the lowest level. Consequently, Figure 19 indicates that an integrated project delivery approach (e.g., IPD and DB) provides an increased ability to impact project costs compared to the traditional, fragmented delivery approach (e.g., DBB). Therefore, having an integrated partnership during the early design stages benefits all key stakeholders, including preconstruction teams (more reliable conceptual estimates), design teams (less re-design in later phases), and owners (better cost management).

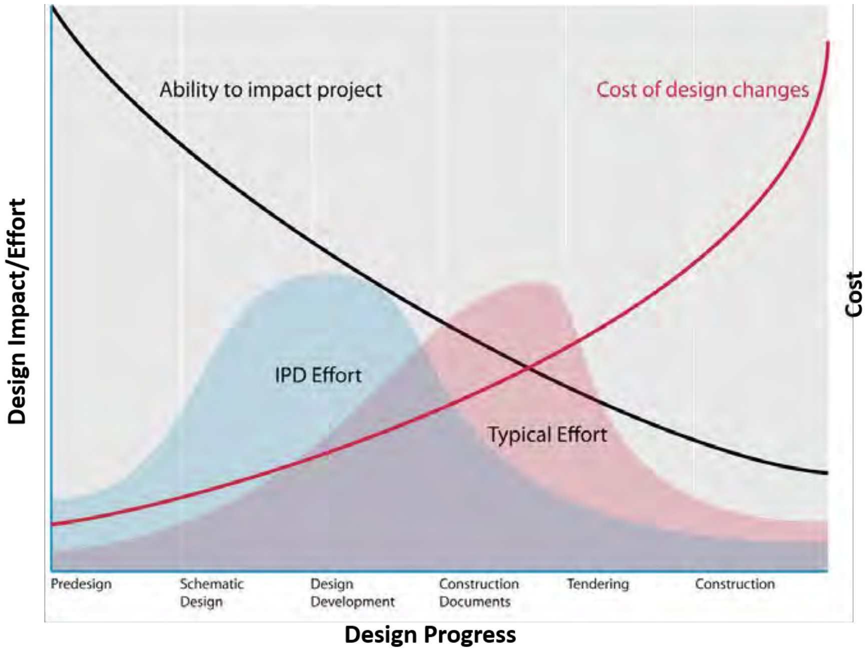

Figure 19. Impact on Design and Cost Based on Project Delivery Methods.

However, creating and maintaining the partnership requires some initial extra effort from all project team members to overcome potential conflicts. In general, to resolve potential conflicts, all stakeholders need to work as a team to make a realistic assessment of their constraints, requirements, and possibilities. In addition, they need to balance between their anticipated effort and benefits (as shown in Figure 20).

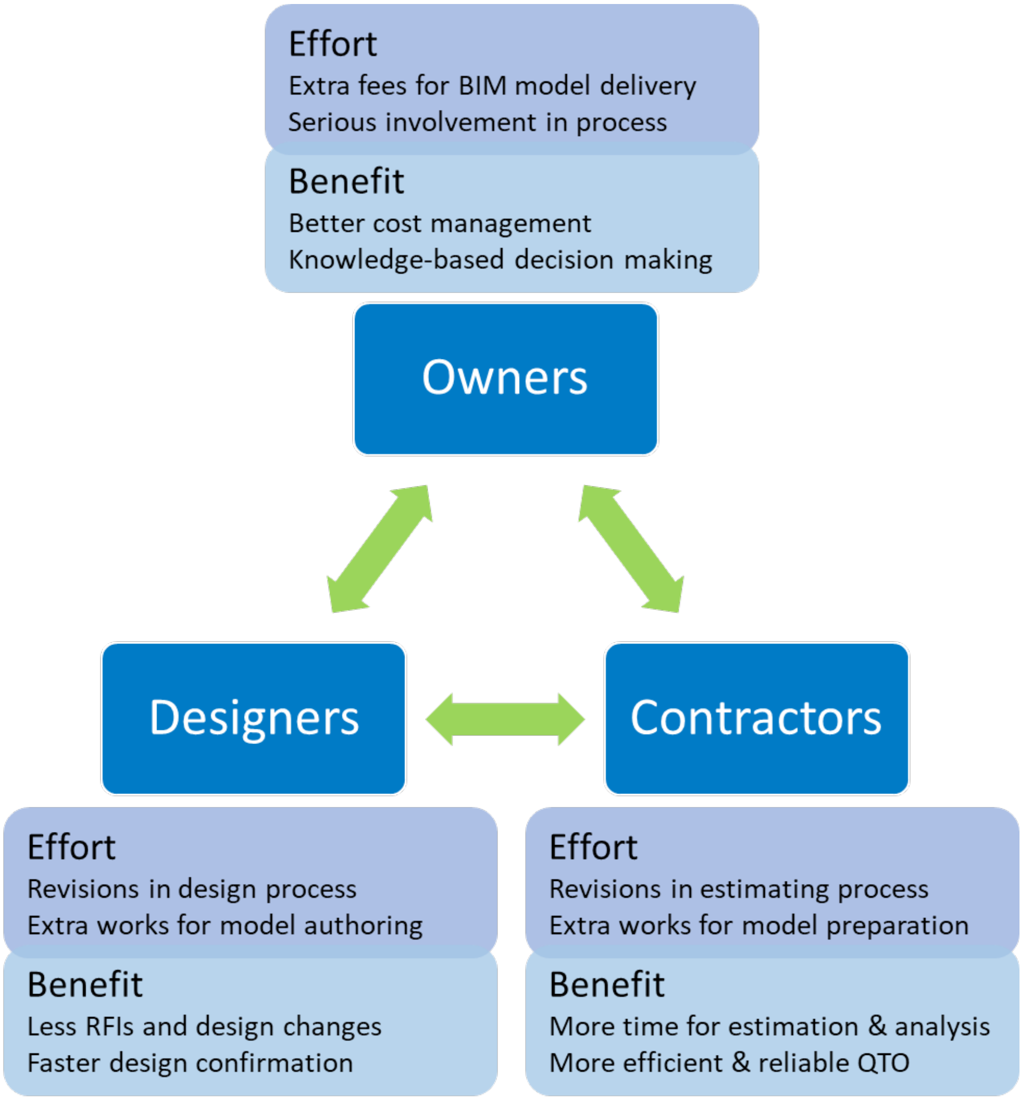

Figure 20. Balance between the Stakeholders' Effort and Benefits.[3]

3. Image Credit: Daniel Davis, Content modified

In the case of adopting MBEst, a typical conflict occurs during the early design stages when design teams do not want to share detailed content as their design is still abstract. At the same time, preconstruction teams want to receive more design detail content to determine their main cost drivers and shape their bid packages. To manage this partnership conflict, preconstruction and design teams should revise their internal processes and determine shared milestones in accordance with their collaboration framework agreements to help create a shared understanding about design development and estimating assumptions and accuracy. Furthermore, design and preconstruction teams should comply with the following principles: (1) avoid an increase in design scope or staff effort (unless an extra fee is approved in advance), (2) avoid compromising design representation (i.e., adding unnecessary details to the representations when architects and engineers are strategically abstract in conceptual and schematic stages of design), (3) avoid relating estimate inaccuracies to model incompleteness and quality issues as the submitted model is developed during design phases, and (4) avoid deviations from agreed design and estimation processes.

Ultimately, adopting MBEst is a gradual process that includes a learning curve for all project members. In particular, designers need to adopt a new mindset to shift the focus from design and visualization to creating model information. Concurrently, preconstruction teams need to accept that model improvement/conditioning and data validation take extra work in order to take full advantage of automated QTO and cost visualization. In addition, owners need to contractually require delivery of BIM models and execution of MBEst while supporting design and preconstruction teams in this process.

MBEst Adoption and Training

Similar to any new technology, an organization needs comprehensive planning to adopt MBEst and to provide adequate training to its relevant staff. This technical report identified two general approaches for training preconstruction teams: BIM champions and distributed training.

Preparing a BIM champion: the first approach is to train a few staff members, usually from the BIM/VDC department, for the purpose of developing a new BIM-based practice or workflow in all intended projects. A qualified candidate would be a BIM expert who already has considerable BIM knowledge and experience. The simple logic of this approach is to appoint the job to staff who are most capable to accomplish it. Once the training is completed, BIM champions would be responsible to get involved in different projects as needed to carry out BIM-related activities. However, this approach has several drawbacks when adopting the MBEst workflow. For instance, BIM experts usually do not have cost estimating expertise, so they do not know how to generate or organize a QTO schedule that is readily useable for estimating purposes. Moreover, some estimators do not rely on quantities received from BIM experts if they had no control of generating them. Additionally, BIM champions are often not deeply involved enough in a project to be able to provide the best BIM practice that fits the specific project's requirements. Finally, dependency on individuals outside of the project teams may cause conflicts between different projects' schedules and timelines and increase the overall duration of projects.

Providing distributed training: The second approach is to create a training program and consistently provide it to all preconstruction team members (including project engineers, managers, and estimators). The logic behind this approach is to have every involved team member onboard for adopting and implementing a new BIM workflow/practice and to empower each team member to take advantage of BIM capabilities in their area of expertise. However, this approach also has some disadvantages when using the MBEst workflow. First, it is a relatively time-consuming and expensive training approach. In addition, adopting some parts of the MBEst (like any other BIM technology) needs an advanced level of BIM knowledge and experience. In this condition, the amount of time/effort required for training and practicing the MBEst workflow may constrain preconstruction team members from accomplishing their primary responsibilities. As a result, they may easily give up on trying the MBEst and shift to traditional methods.

What may be more realistic during the early adoption of MBEst is a hybrid of these two strategies. A preconstruction business unit may choose to selectively cultivate and train preconstruction estimators in MBEst. These "super users" then support their offices in developing and sustaining MBEst practices until these practices become more widespread in the firm.

Currently, the BIM market is rapidly evolving. The increasing number of BIM practices, services, and tools has convinced GCs that including BIM experts in their preconstruction teams is not only inevitable, but significantly beneficial in order to take advantage of BIMs being developed for design purposes. Moreover, there is a growing demand for integrated and BIM-based collaboration, communication, and project delivery, which in turn requires a minimum level of BIM skills and understanding among all team members. Therefore, many GCs have realized that they need to create an optimized lean solution through merging these two general training approaches. Therefore, preconstruction teams should define some levels of BIM skillsets suitable for different purposes and team members and then provide training to staff based on their mandatory skill levels. This report presents a categorization of BIM skillsets required for adoption and implementation of the MBEst workflow. Having everyone in the estimating and preconstruction department with some basic BIM skills will allow staff to become more confident in their capabilities when using modeling technology for estimating. Also, increasing staff education in BIM will support adoption and innovation.

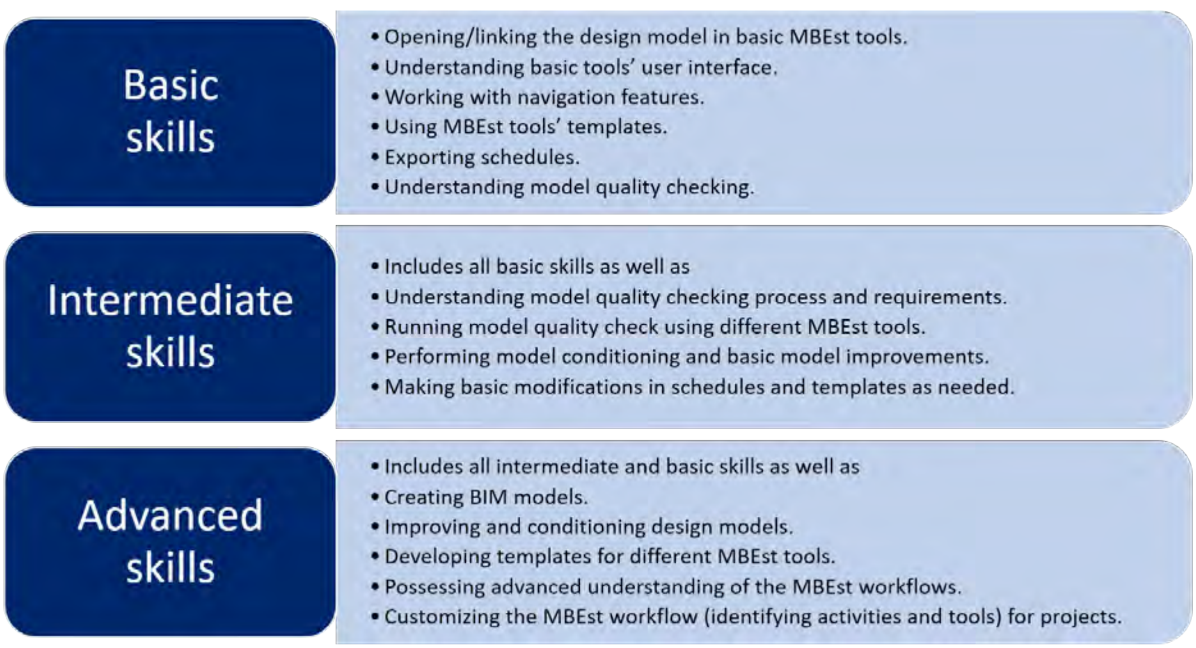

Figure 21. The MBEst Required BIM Skillsets.

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