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**Investigating Factors that Influence the Implementation of Model-based Estimation**

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**Abstract**

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Model-based estimation (MBE) has become more common in recent years in the construction industry, with many seeking to capture the potential of Building Information Modeling (BIM). However, MBE is neither utilized as widely as expected nor implemented as efficiently as it could be in current industry practice. Aiming to give advice to the future industry in improving MBE implementation, the present study target to find a list of factors that have positive impacts on MBE implementation. Previous studies attributed the low level of MBE implementation to a low level of model sharing and lack of required information in models, largely due to lack of integration between design and construction and the absence of effective communication among project participants. Thus, the cooperation between two major project participants, namely designing team and general contractor, appears to be a crucial factor in determining the level of utilization of MBE. To this end, the present study mainly focuses on

testing a hypothesis that a correlation exists between the level of project integration and the level of MBE implementation. This study used an online survey as a main research methodology to collect responses from industry practitioners, and a statistical analysis was conducted to test the hypothesis. The study results will support project teams in devising ways to improve the level of MBE implementation for future projects.

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# Chapter 1. INTRODUCTION

## 1.1 PROBLEM STATEMENT

Model-based estimation (MBE) refers to using Building Information Modeling (BIM) technology for estimating purposes. MBE is considered one of the most potential and profitable applications of BIM in the construction industry. As a result, the MBE feature is developed and added to basic modeling tools such as Revit, and model-based project management tools such as Navisworks, Vico and Innovaya. However, it is known that MBE is neither utilized as much as is expected nor implemented as efficiently as it could be in the current industry. Previous studies attributed this to a low level of model sharing and lack of required information in models, which is largely due to a lack of integration and absence of effective communication among project participants (e.g., Aram et al., 2014). Thus, the cooperation among major project participants, namely the owner, the design team, the general contractor, and the key subcontractors (such as mechanical and electrical) appears to be a crucial factor in determining the level of utilization in MBE.

However, there have been only few studies specifically aimed at investigating what impacts such cooperation that is required for MBE. In response, the main objective of this thesis is to investigate correlations between the level of project integration and the level of MBE implementation. The author believes the study results will support project teams in devising ways to improve the level of MBE implementation for future projects.

## 1.2 HYPOTHESIS

In this thesis, the author will try to test a series of hypotheses about correlations that may exist between project integration and three MBE indexes such as:

- MBE efficiency
- MBE implementation frequency
- Percentage of building systems and trades being estimated with MBE tool.

MBE efficiency levels, which will be discussed further in following chapters, measure the degree of estimating performance in terms of time and cost saving. MBE frequency level would show the number of times of estimating revisions based on design changes in the pre-construction period of the project. MBE percentage can be derived by dividing the total cost estimated with MBE tools by the total construction cost.

Those are the three various aspects of MBE implementation. Thus, this thesis aims at testing the following three main hypotheses:

- Hypothesis 1: Project integration has a positive effect on MBE efficiency level.
- Hypothesis 2: Project integration has a positive effect on MBE implementation frequency level.
- Hypothesis 3: Greater project integration will result in a greater percentage of building systems and trades estimated based on the model.

Project integration means in the context of this thesis that the major project participants team up in the preconstruction phase, collaboratively develop and validate project goals for project success, and continue to work together throughout the entire project.

In addition to the three main hypotheses, the author will also study on the relationship between MBE indexes and other factors such as: project delivery method, project type, budget level, and owner type, which may also have influence on MBE implementation.

## Chapter 2. LITERATURE REVIEW

### 2.1 MODEL-BASED ESTIMATION

#### 2.1.1 *Development of Technology of Model-based Estimation*

The implementation of BIM in the construction industry is on the rise. BIM, as a tool that can bring better efficiency of design and construction operations, has potential to be used in many aspects in the construction industry, including cost estimation.

It is believed that MBE can benefit the project by automating the process of estimation, such as quantity take-off (QTO) (Sattineni et al., 2011). Monteiro et al. (2013) tested the feasibility of BIM as an automatic QTO tool, and concluded that using BIM in estimation can bring many advantages, such as estimating accuracy and saving expenses and time when compared to the traditional manual QTO that is error-prone and time-consuming. Thus, it is believed that MBE is one of the most profitable applications for BIM (Monteiro et al, 2013). Shen et al. (2010) also in their study tested the effectiveness of MBE. The result of the study shows that MBE has better performance than that of the traditional estimation method for the entry-level users, and that the more complicated the estimation is, the more benefits it can receive from the MBE (Shen et al., 2010).

To summarize, the benefit MBE could bring to projects is that it could automate the QTO process of estimation, which as a result:

- (1) Enhances accuracy of estimation,
- (2) Saves in expense and time, and
- (3) Assists entry-level users in improving their performance during the estimation process.

Since MBE is one of the most promising applications of BIM, and could bring some of the many advantages listed above to projects, many studies have conducted with aims to find out how to use BIM in estimating efficiently and effectively.

In technological aspects, Lee et al. (2014) applied the ontology approach to help estimators to find work items in the model easily, and this is proven to be effective in case studies (Lee et al., 2014). Ma et al. (2014) also established an approach to export data from the BIM model systematically, which is believed to be able to facilitate the future development of automatic MBE (Ma et al., 2014).

In addition to improving MBE efficiency via technological approaches, researchers are also conducted to explore the possibility in making a difference via the management approach, such as developing feasible workflow and knowledge-based frameworks for pre-construction management. For example, Choi et al. (2015) developed a model-based QTO prototype system, which can facilitate early stage design decision making process by increasing the accuracy and reliability of early stage estimating (Choi et al., 2015). The research suggested a process of doing early estimation, which consists of four steps:

- (1) Analyzing level of development (LOD),
- (2) BIM modeling,
- (3) Checking the model's quality, and
- (4) Using the QTO prototype system to produce early stage estimations

In Aram et al. (2014) 's study, a knowledge-based framework for QTO and cost estimation was developed to solve problems that commonly happen in MBE implementation; e.g., design model is in low quality or estimators find it hard to use MBE tools. The framework includes

domain, reasoning, task and interface layers. Implementation of the framework would support better performance of MBE tools. (Aram et al., 2014).

### 2.1.2 Model-based Estimation Workflow

The author evaluated five popular MBE tools that are widely used in the industry in recent years. This section summarizes their basic estimating steps:

#### (1) Revit

A user could acquire quantities in Revit by creating a schedule. The first step is to choose the element that is needed to estimate from the model, and Revit could usually list categories of items at the left side of the dialog box (as highlighted in Figure 2.1) for the user to choose from. However, prior to that, the user should check if the model items are correctly categorized.

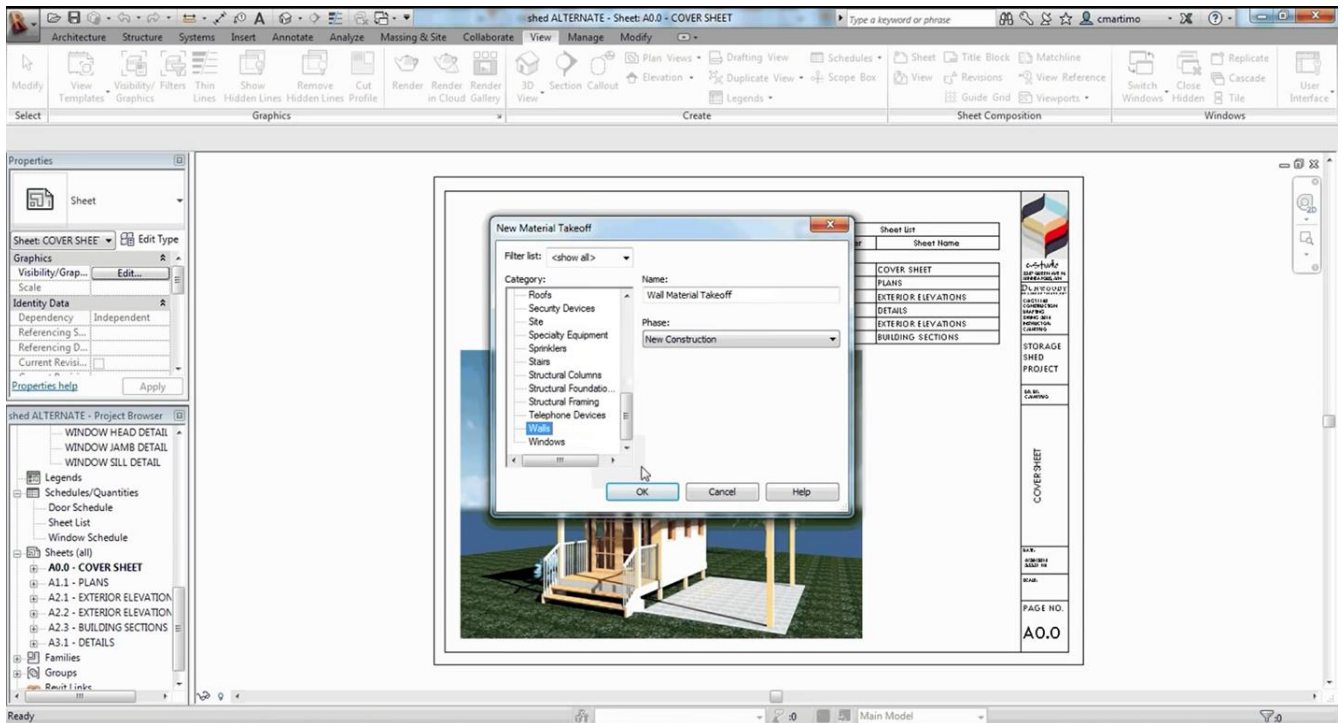


Figure 2.1. Revit Estimating: Choose Element (Martimo, 2014).

In the menu, the user should be able to choose the parameters such as length, volume, or area of that building element category to show on the schedule (Figure 2.2).

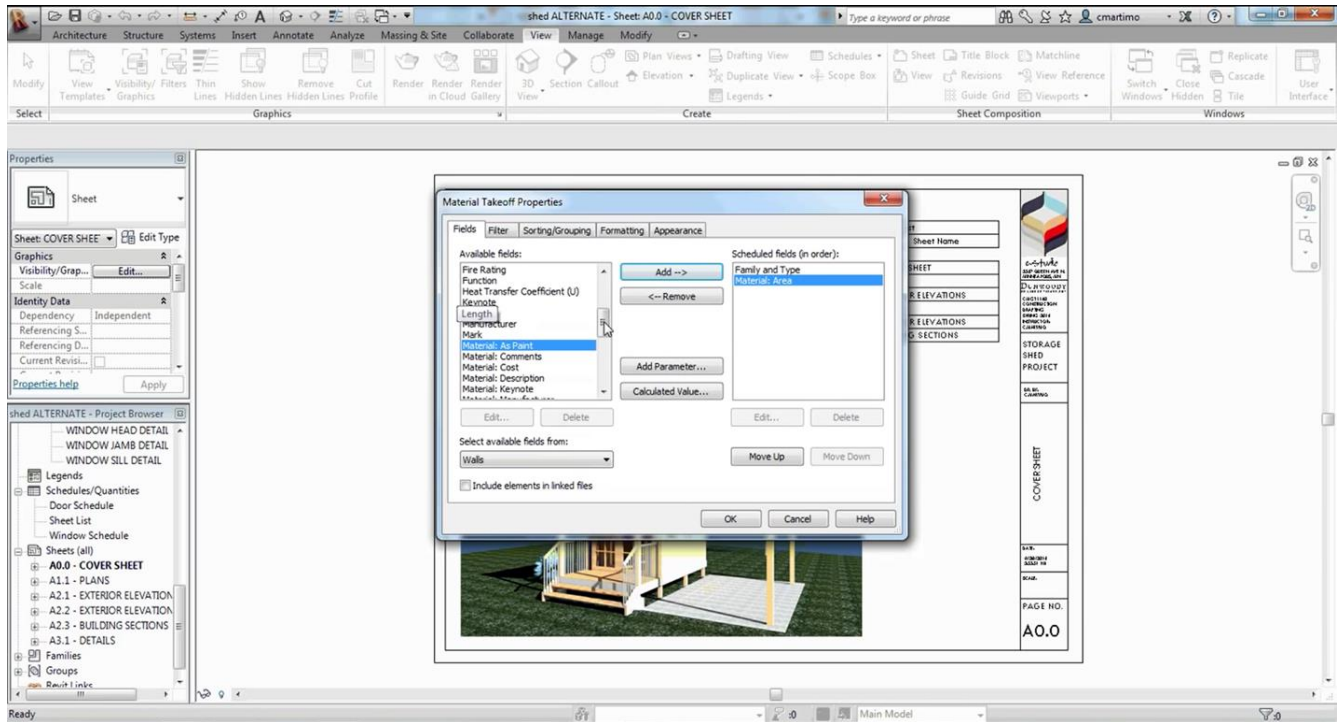


Figure 2.2. Revit Estimating: Choose Parameter (Martimo, 2014).

The user could also sort and group items based on self-defined rules (Figure 2.3).

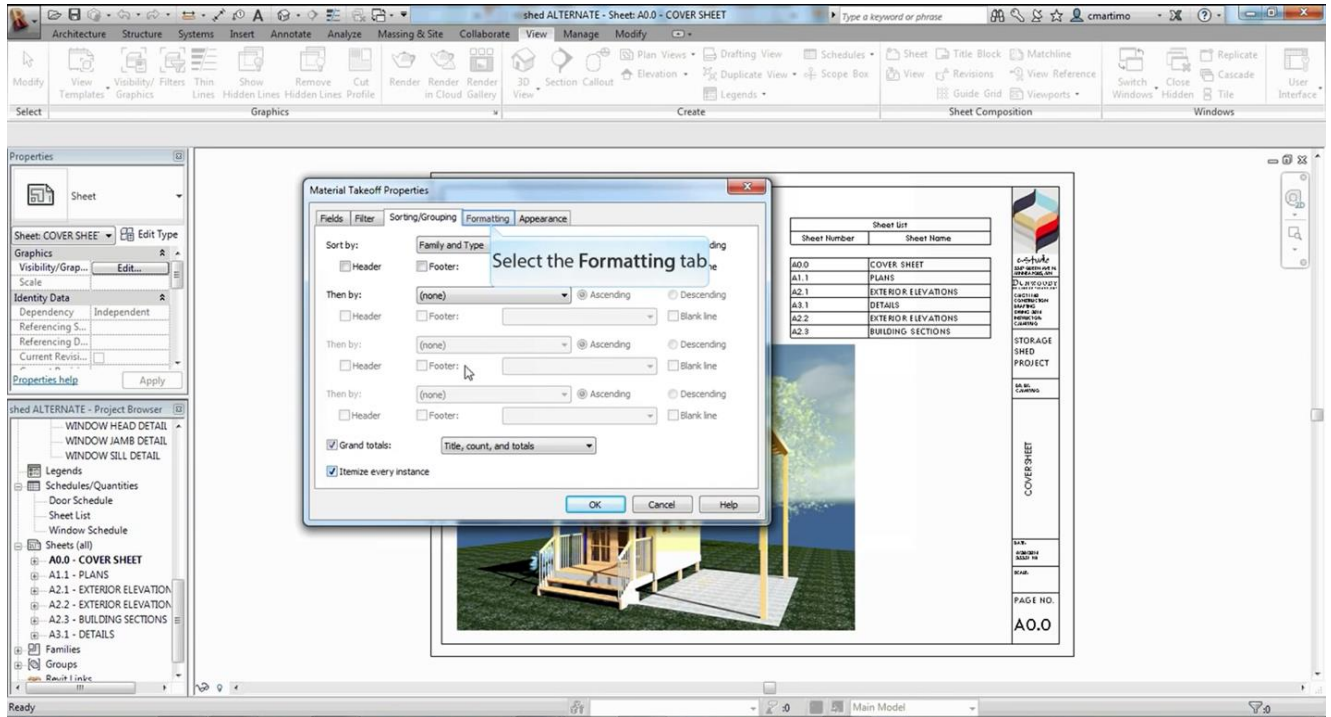


Figure 2.3. Revit Estimating: Sort (Martimo, 2014).

The schedule can show the quantity of each item (Figure 2.4). The user can also insert a unit cost to price the item, and by adding the calculated value, the user could add formulae and manipulate parameters to calculate the total cost of the selected model item.

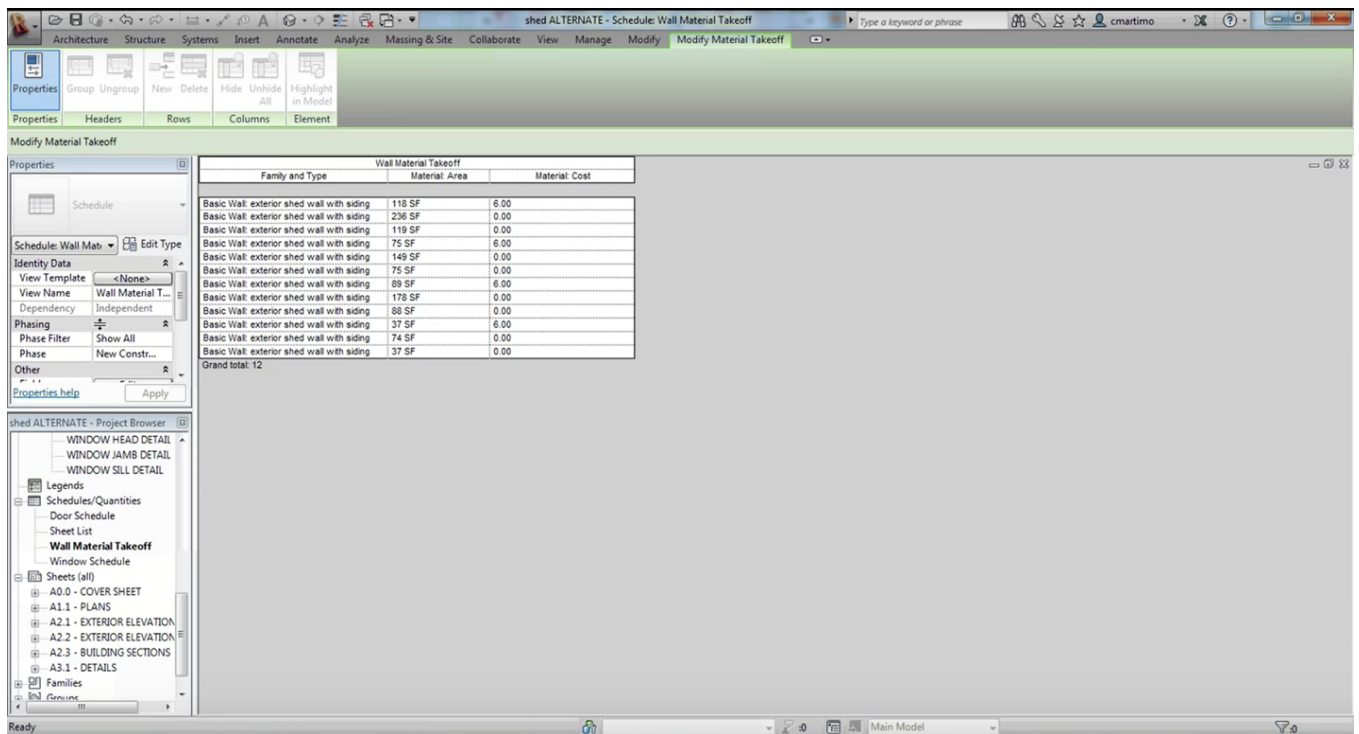


Figure 2.4. Revit Estimating: Schedule (Martimo, 2014).

## (2) Navisworks

The first step of using Navisworks to do the MBE is to select and categorize building elements. A user can either manually select the element one by one, or use the selection set that has been already defined, which may either be provided by their company or created and implemented in their previous projects (Figure 2.5). If the user chooses to select items manually and group them as a selection set, then it is not necessary to verify whether or not the model items are well defined and correctly classified. However, if the user chooses to use a selection set, which applies rules to select items automatically, the user should make sure that the model is built in good quality.

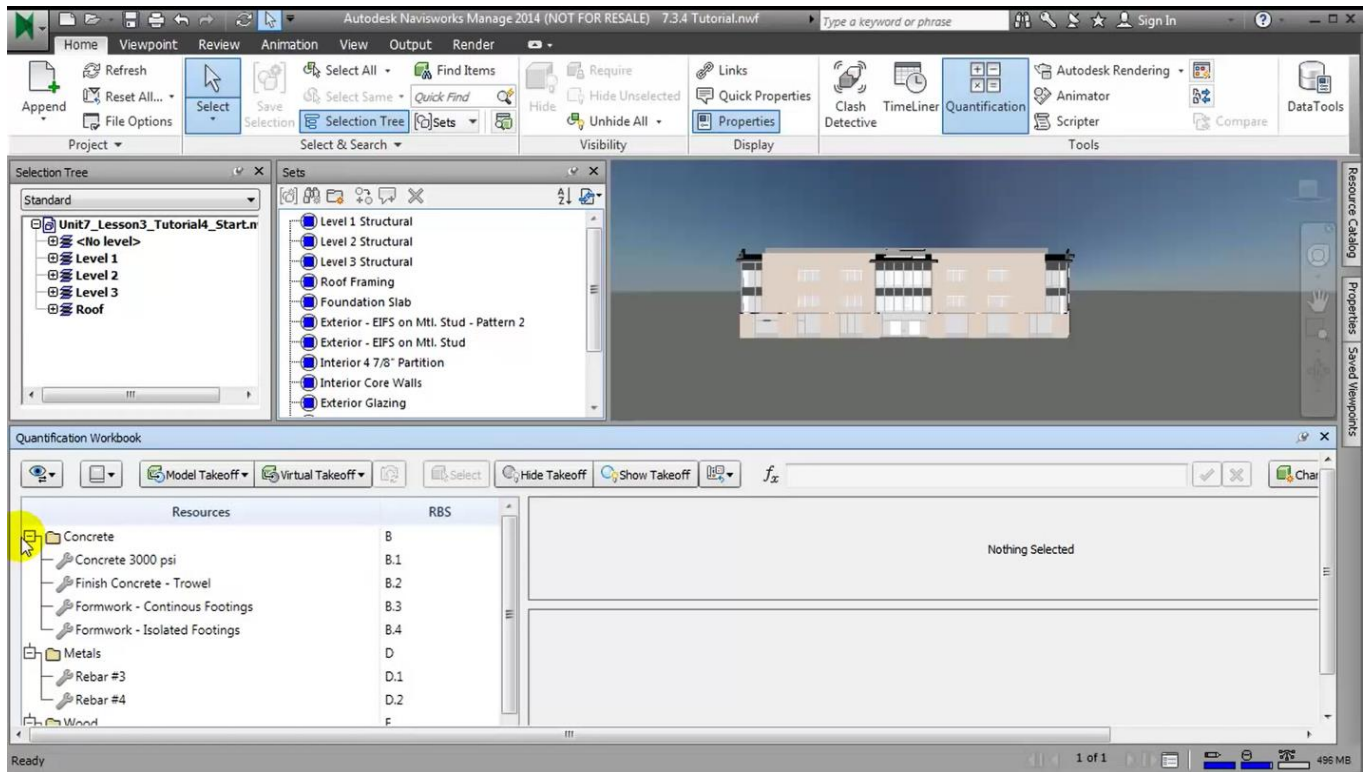


Figure 2.5. Navisworks Estimating: Select Building Elements (Autodesk Education, 2013).

In the next step, the user should be able to assign the selected elements to the item catalog with a pre-defined work breakdown structure (WBS), which usually is based on MasterFormat or Unifomat (Figure 2.6). After that, the quantity will be shown in the workbook, and the user can easily make adjustments or apply formulae to the quantity that is shown on workbook. The user could also edit resources and assign it to the selected items to further calculate the price (Figure 2.7).

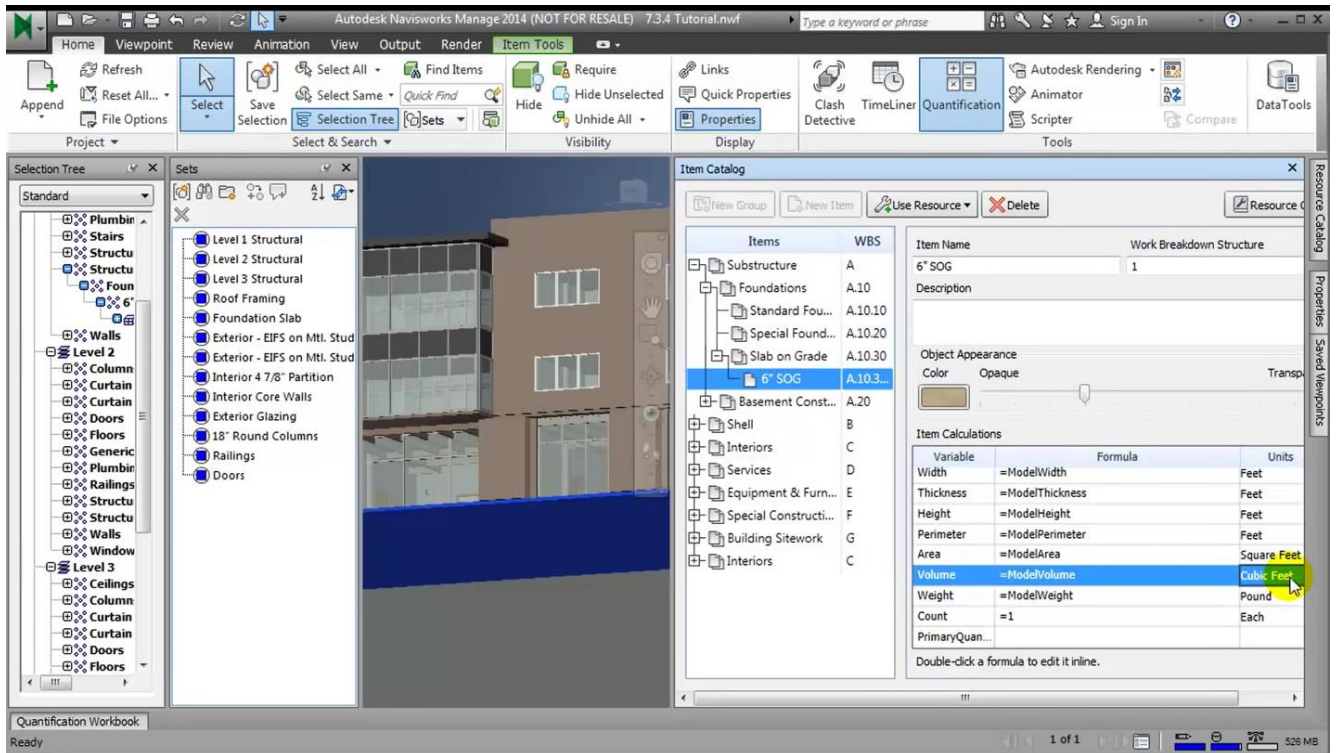


Figure 2.6. Navisworks Estimating: Match Quantity and Adjust Quantity (Autodesk Education, 2013).

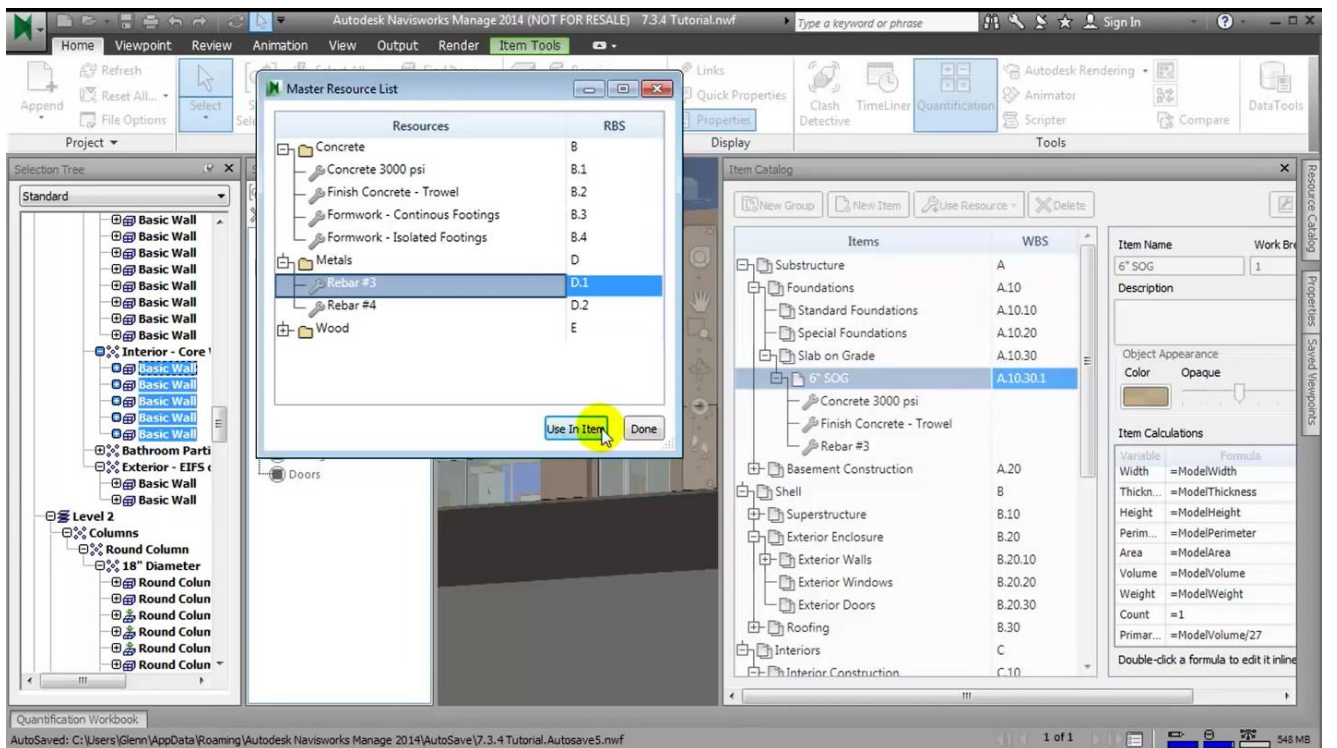


Figure 2.7. Navisworks Estimating: Edit Resource (Autodesk Education, 2013).

### (3) Autodesk QTO

After importing models to Autodesk QTO, the building elements are categorized automatically in the software. A user can either take off each categorized item one by one, or take off the whole model just by clicking the model option in the takeoff menu (Figure 2.8).

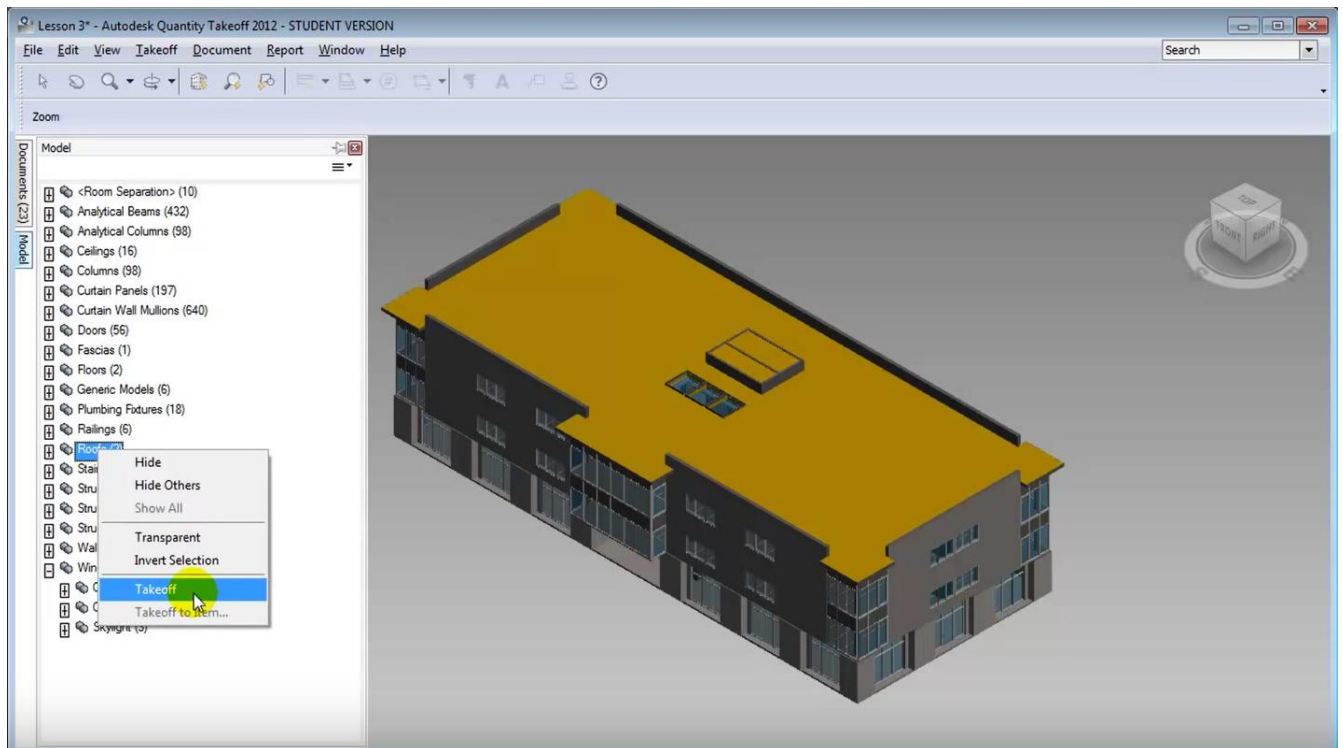


Figure 2.8. Autodesk QTO Estimating: Take-off (Autodesk Revit Tutorial, 2015).

The user then needs to manually match the take-off quantity to the WBS system (Figure 2.9).

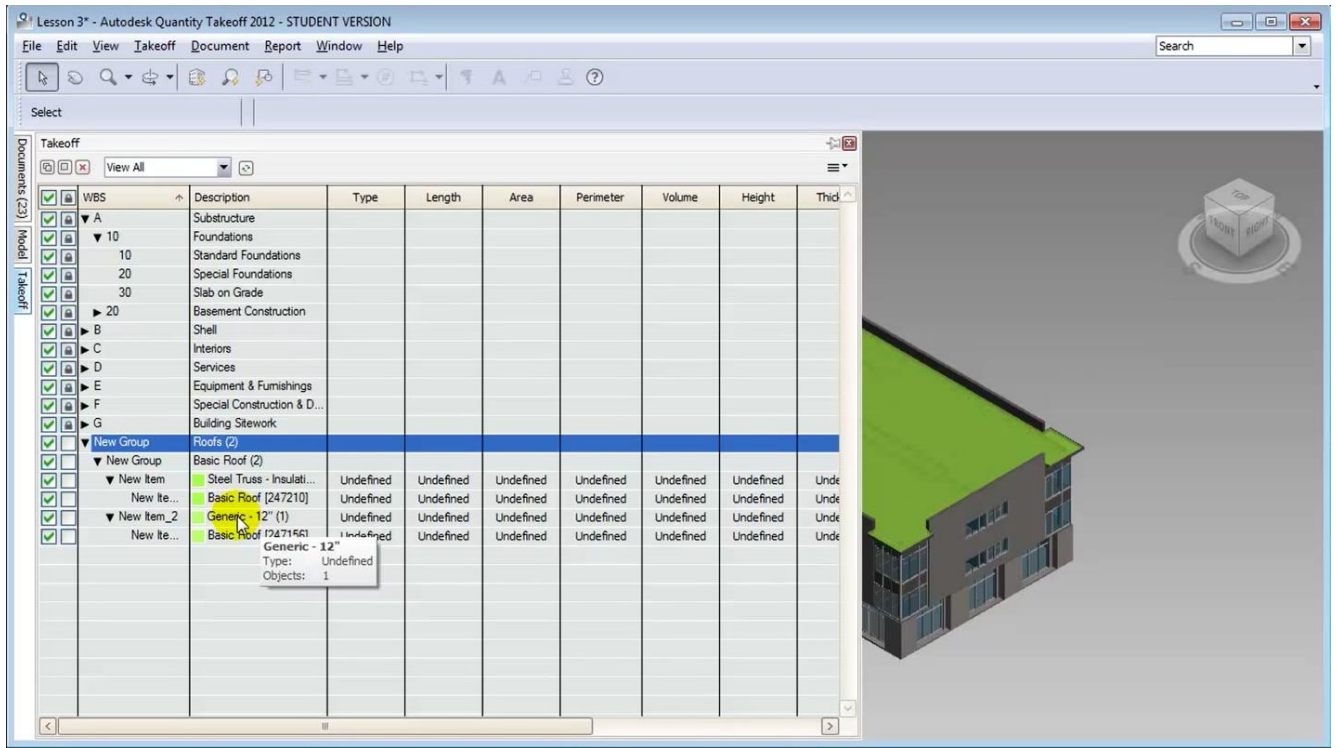


Figure 2.9. Autodesk QTO Estimating: Match (Autodesk Revit Tutorial, 2015).

The user should also choose the primary parameter to be included in the QTO, such as length, area, and volume, by setting the type of that item category in the settings. If the category is not defined, it would not be shown in the final QTO report (Figure 2.10).

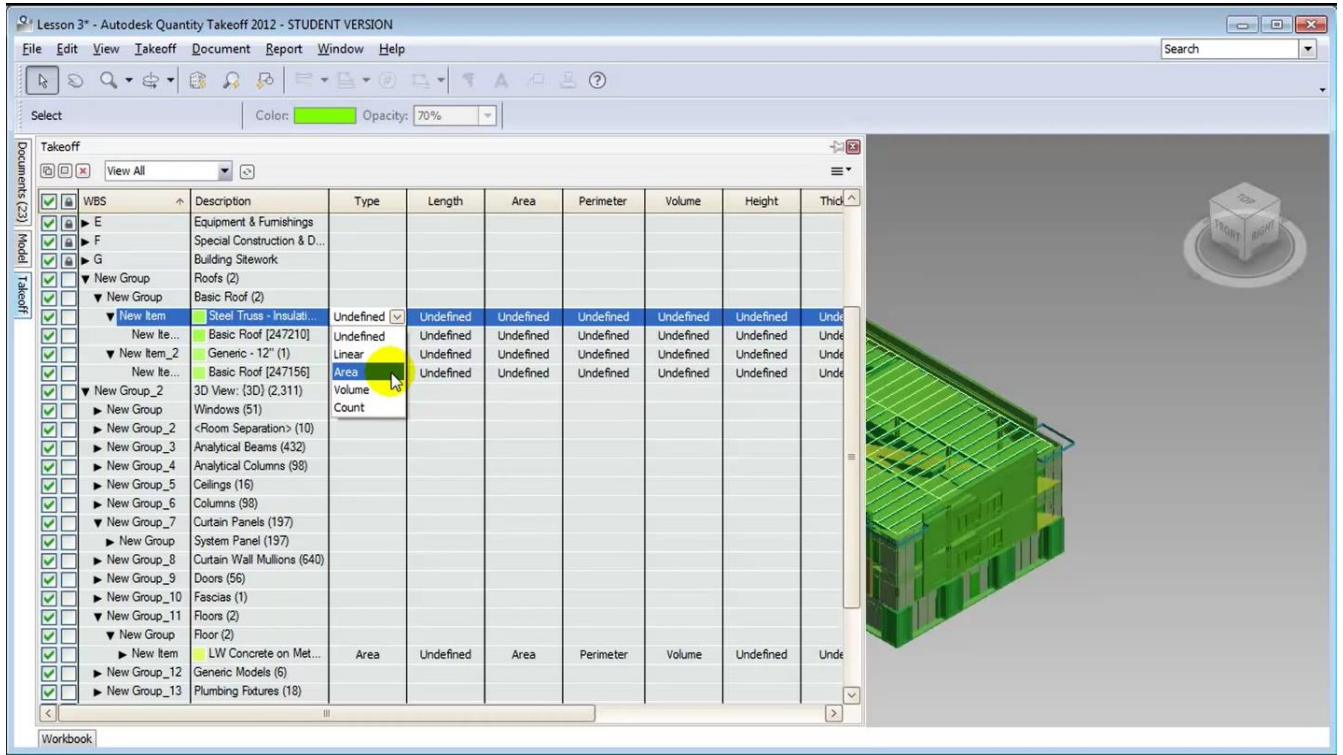


Figure 2.10. Autodesk QTO Estimating: Choose Parameters (Autodesk Revit Tutorial, 2015).

After choosing which parameter to show on the final report, the user could apply formulae to the parameters to adjust the numbers. After that, the user could price the project by inserting cost information to the software. The user can choose either to price it based on their self-performing plan (labor, material, and equipment costs), or subcontracting (Figure 2.11).

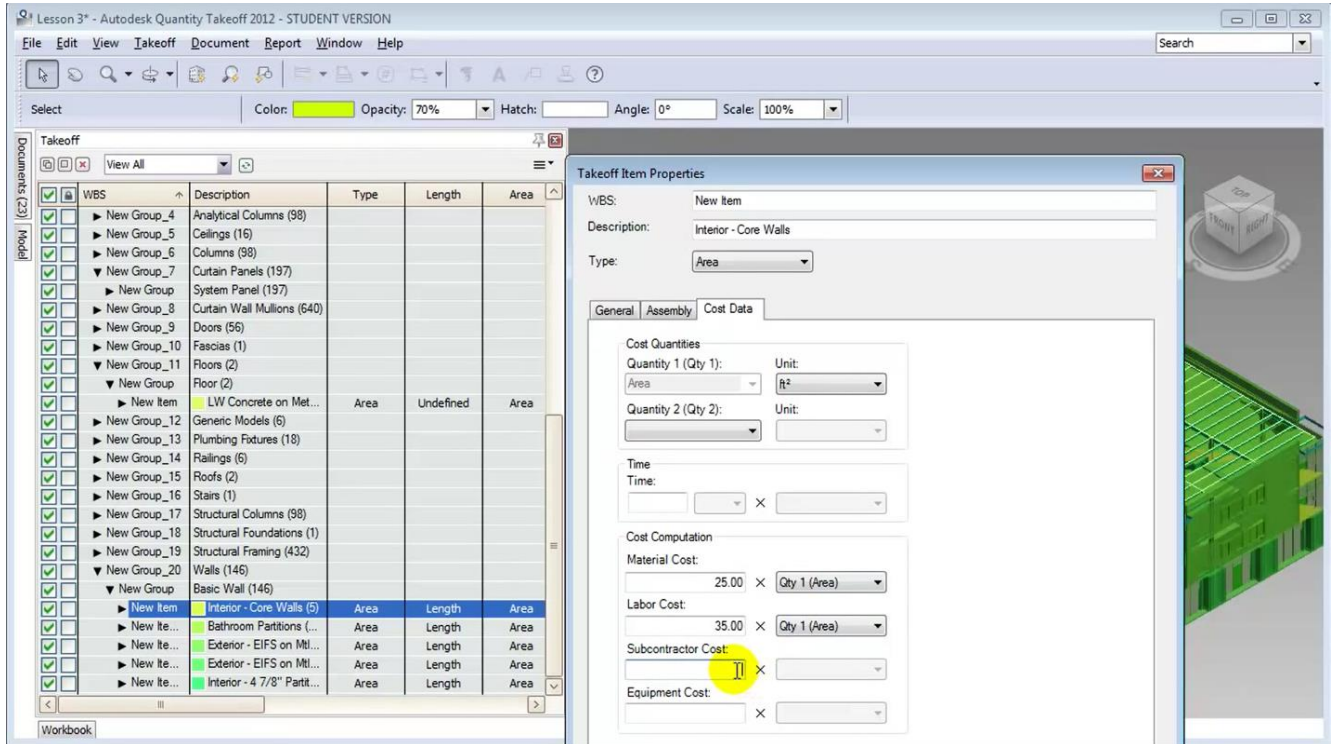


Figure 2.11. Autodesk QTO Estimating: Pricing (Autodesk Revit Tutorial, 2015).

#### (4) Vico

The building elements are taken off directly from the model and are categorized automatically in Vico. All parameters, such as length, area, and volume of each element, are calculated automatically, and could be shown in a quantity list (Figure 2.12).

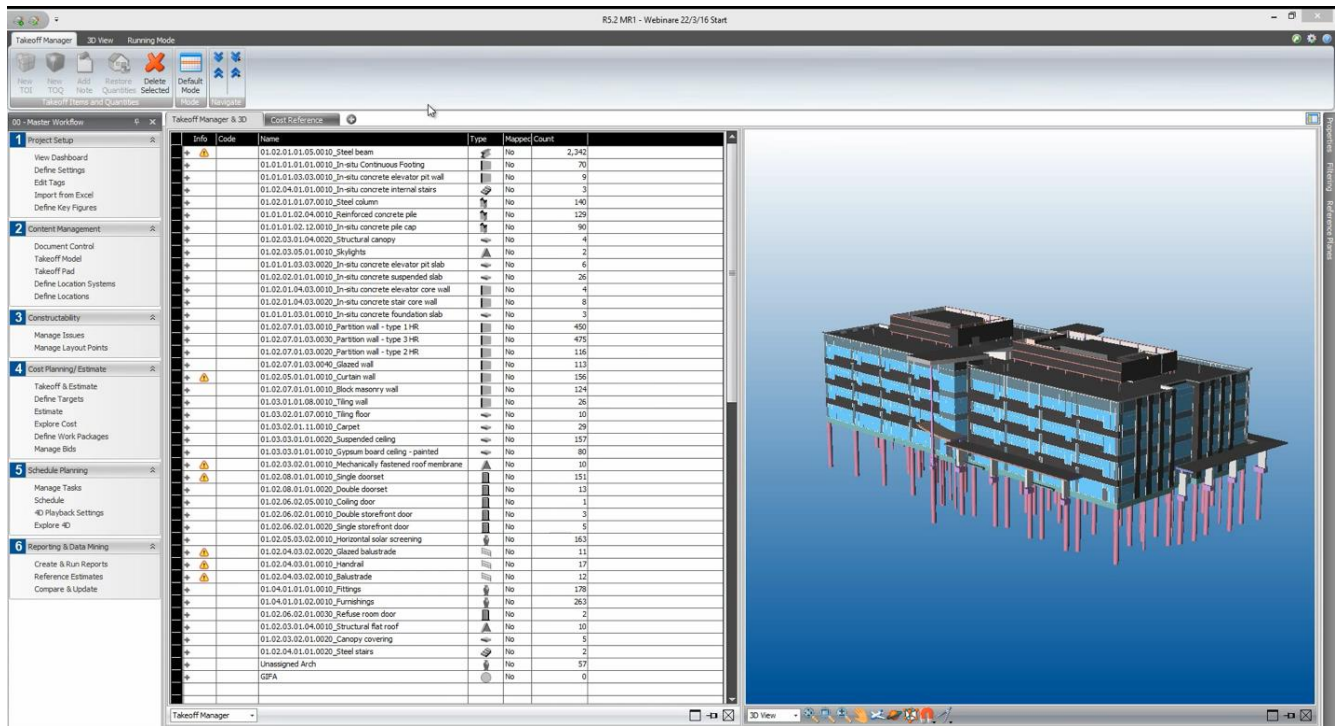


Figure 2.12. Vico Estimating: Take-off (Osment, 2016).

The user can then drag the needed quantity from the quantity list into a pre-defined WBS chart. After that, the user can insert the unit cost of each line item. Another feature that Vico could support is to compare quantity changes being made to the previous estimate. This feature is especially useful in situations where a significant amount of changes happens to the design (Figure 2.13).

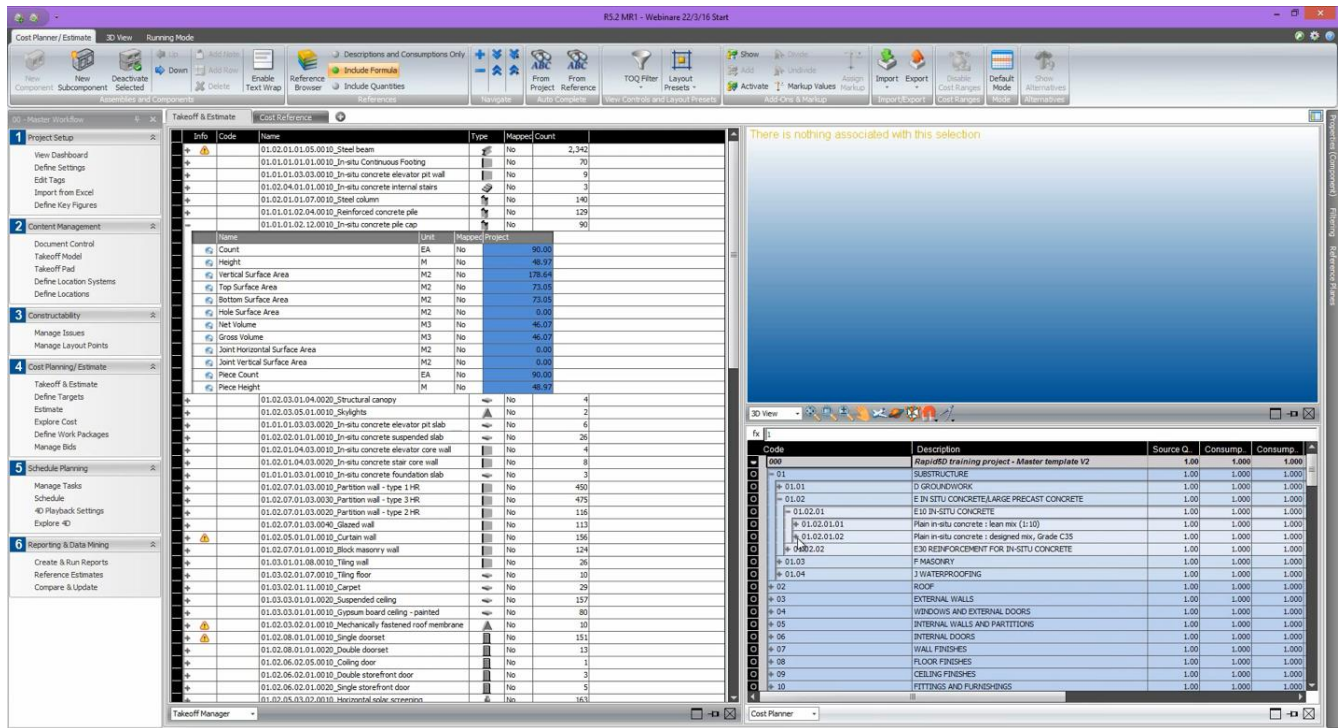


Figure 2.13. Vico Estimating: Match and Pricing (Osment, 2016).

### (5) Innovaya

After importing models to Innovaya, building elements are automatically categorized based on different systems and locations. The quantities are also taken off automatically (Figure 2.14).

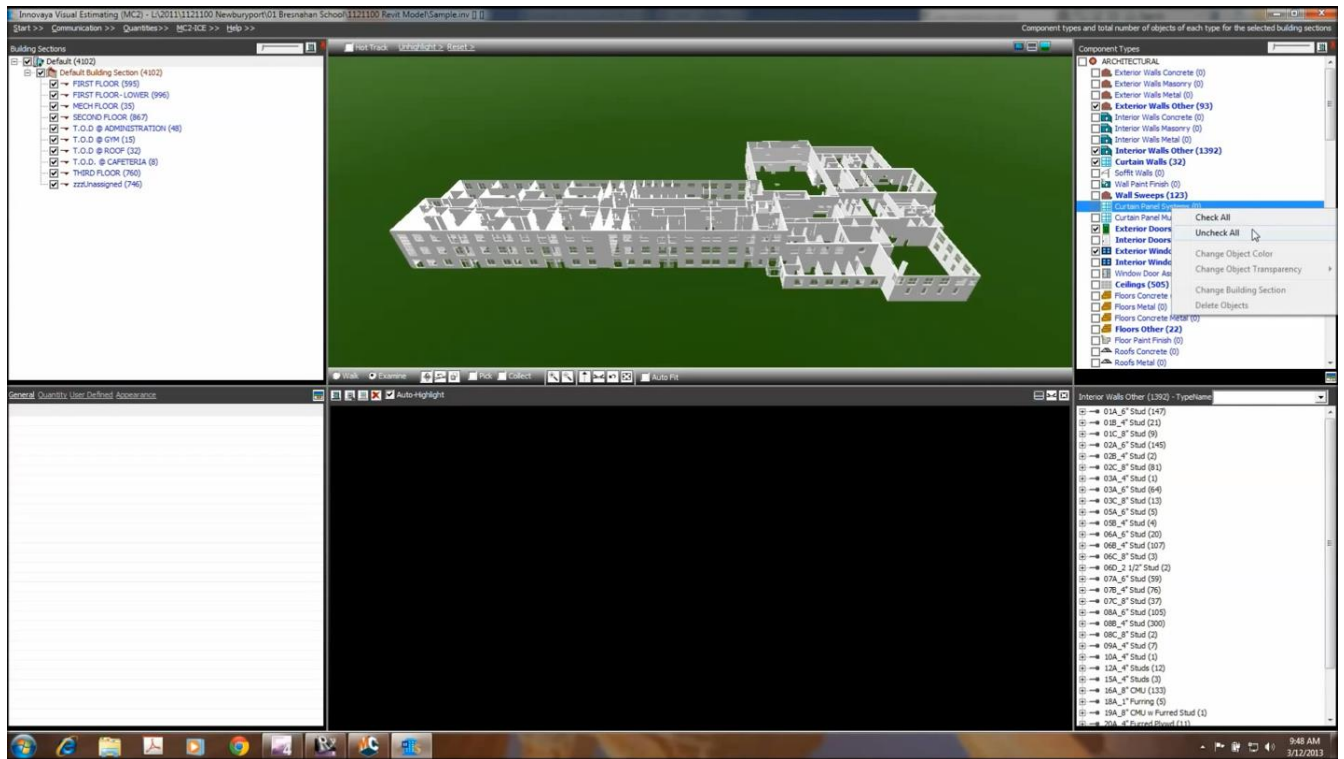


Figure 2.14. Innovaya Estimating: Take-off (Burge, 2013).

Then, a user can start to use the quantity of each model geometry as a reference and drag them into each pre-defined WBS. The user can also conveniently choose the material and other price-related options of the item (Figure 2.15).

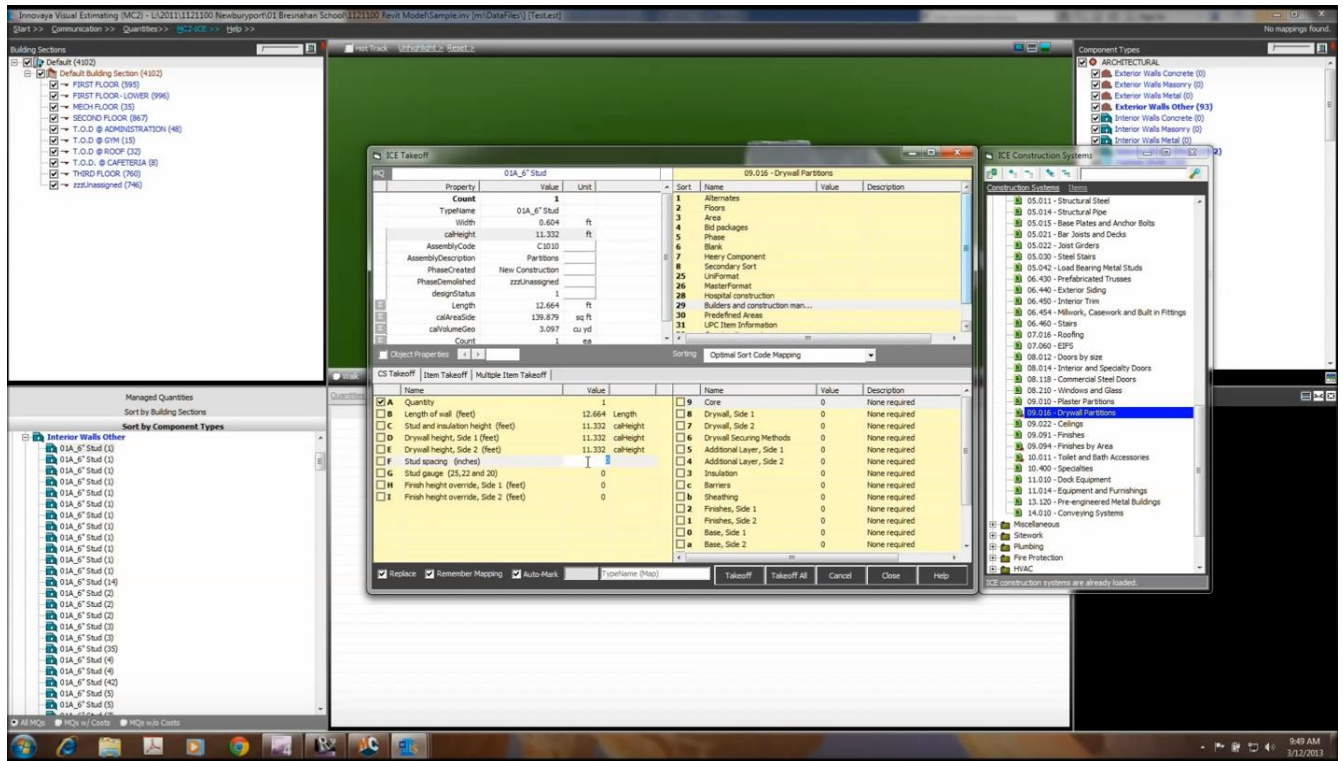


Figure 2.15. Innovaya Estimating: Match and Pricing (Burge, 2013).

All of the five major tools have their own advantages and disadvantages. For example, Revit, as a modeling tool, could show the quantity of each model element, and a user could add unit prices and apply formulae to calculate their total cost. However, it does not have a built-in WBS for a user to create a quantity report. Navisworks, as a model reading tool, has a feature of extracting quantities from models, and it provides options either (1) to automatically search and select model items by applying self-defined rules, or (2) to manually select model items one by one, which as a result makes it very flexible in categorizing model items. However, as mentioned earlier, to implement Navisworks in automatic QTO, model element selecting rules have to be carefully defined with priority assigned in the beginning of estimating. Autodesk QTO, Vico, and Innovaya are similar in terms of estimating steps. They could automatically categorize model items, and provide a WBS system for a user to follow to keep estimates clean and organized.

Based on the review, it is observed that all MBE tools share some of the same processes and can be summarized into the followings:

- (1) Categorizing models based on location and construction systems
- (2) Putting quantities of construction elements into construction division systems that are consensus by the industry such as Masterformat and Unifomat.
- (3) Apply formulae and setting unit price for each item.

Table 2.1 shows and compares the characteristics of the five tools:

Table 2.1. MBE Tools Comparison

	Built-in WBS	Automatically Categorize Model Items	Able to apply formula and set price
Revit		√	√
Navisworks	√		√
Autodesk QTO	√	√	√
Vico	√	√	√
Innovaya	√	√	√

When studying these five MBE tools, the author noticed that if the process of categorizing model items is automatic, it is important to verify the quality of the model to determine if every model item is well-defined in the original model. Otherwise, MBE would not be able to be implemented well in the project. For example, if a wall element is defined as a column in the model, its quantity given by the MBE tools in the report or schedule will not be accurate.

In case the model is of low quality (e.g., building elements are poorly defined), there are many actions that a user could consider taking when implementing MBE. First, the user could

take time adjusting the model and making it more suitable to implement MBE with, or the user could select model elements one by one manually. Second, in some cases the user could communicate with the design team and request a model with a higher quality. The issues regarding the model quality and possible actions that could be taken by the user will be discussed further in the following chapters of this thesis.

### 2.1.3 *Challenges Faced by Model-based Estimation*

Although a number of studies have been conducted in this area and a number of creative solutions have been developed and MBE has gained popularity in recent years, MBE implementation is neither utilized as much as is expected in the total project cost nor implemented as efficiently as it could be in the current industry (Olsen et al., 2017). To understand the reason behind this and to better implement MBE in the future, a few studies have analyzed the reason for this phenomenon in the current industry.

Monteiro et al. (2013) asserted that although BIM tools offer QTO features, extra effort should still be made to exchange information between design model and management model, because most BIM tools are still limited in terms of manipulating quantity data to produce the final estimation (Monteiro et al., 2013). They mentioned that after quantity data is extracted from MBE tools, the data usually needs to be transformed from MBE tools to another cost estimation software. That is required in many cases, because while studying popular MBE tools in Section 2.1.2, the author observed that most MBE tools do not have built-in database containing the cost information of material, labor, and equipment of building elements. This process of transforming data to another software can lead to reduced efficiency of MBE, or even data loss.

On the other hand, Sattineni et al. (2011) argued that the main reason for low implementation rate is a result of the BIM operators' lack of skills in estimating (Sattineni et al.,

2011). Performing MBE requires a user to be proficient in both BIM tools and estimation processes, which makes it even harder to implement MBE.

Besides this challenge, there is another issue that has an impact on MBE implementation and happens commonly in the construction industry. It is the lack of detailed information needed for estimation in the model provided by the design team. Aram et al. (2014) pointed out that success in MBE relies on an assumption that information provided by the model is adequate for the estimator to produce the estimating. However, in real-world practices, this is not always the case. In response, the construction team may either ask the design team to revise the model or build a model by themselves. That causes difficulties in MBE implementation (Aram et al., 2014).

Sabol et al. (2008) also explored the challenges in implementing MBE, and found two main obstacles that are still worth noticing in today's industry (Sabol et al., 2008):

- (1) Exchange data between software is challenging, since standard format to organize and share information has not yet been comprehensively developed.
- (2) BIM application is still under development.

To summarize the results from the previous studies, the challenges in implementing MBE include:

- (1) Lack of employees who master both BIM and estimating skills.
- (2) Technology of MBE is still under development.
- (3) The construction industry has not yet set a common standard for estimators to follow while implementing MBE.
- (4) Extra effort needs to be made to exchange data from the design model to the management model. Transforming quantity data from different software can hamper the process of implementing MBE.

- (5) Information sharing is a critical success factor for MBE, yet in the construction industry information provided by the design model typically only provide 50% of the information needed for estimators to produce estimation. (Olsen et al., 2017)

## 2.2 BIM AND PROJECT INTEGRATION

As mentioned in Section 2.1.3, one of the major challenges associated with MBE is related to information sharing. To successfully implement MBE, the level of information sharing among the main project participants represents a critical factor. A satisfactory level of information sharing could refer to the following:

- (1) Information sharing among the main project participants should be performed adequately, meaning that enough information should be provided in the model. An adequate amount of information, in this context, means that the model should meet the Level of Development (LOD) that is agreed upon by the main project participants.
- (2) Information sharing and data exchange should be well planned and executed, inferring that the entire information sharing process should be according to an organized methodology, based on a pre-defined implementation plan.
- (3) The most important aspect in this process is that the information sharing should be completed in a timely manner.

However, as mentioned in Section 2.1.3, information sharing within the current construction industry is not appropriately or effectively executed for estimators to produce estimations from the model provided by the design team.

To resolve this problem, it is believed that improving the project's integration level could make a significant difference. The recent study of Garcia et al. (2016) asserted that the contracting

method of Integrated Project Delivery (IPD) that has a high level of project integration can facilitate an enhanced information exchange among all team members. They also posited that the alignment goal of IPD not only enhances the quantity of information sharing within the project team, but also enhances the quality of information sharing by encouraging team members to search for more effective and crucial information (Garcia et al., 2016). As discussed earlier, a higher level of information sharing means more opportunities for MBE. Thus, it can be concluded that an elevated level of project integration can foster MBE.

On the other hand, many studies suggest that BIM implementation can also enhance the level of project integration and, thus, improve the performance of IPD projects. MBE, as one of the BIM functions, is believed to have the same or similar impact on project integration. For example, Luth et al. (2013) postulated that BIM has the potential of serving design-construction integration. In their research, based on a case study that focused on a University of Southern California project, they concluded that the use of BIM can help limit the number of request for information (RFI) and save costs and time spent on the coordination of the project (Luth et al., 2013). Therefore, the implementation of BIM in a project is expected to make the project team more integrated and, as such, a more integrated project team can achieve project performance that is dramatically enhanced concerning all aspects of the project.

The study of Azhar et al. (2014) also demonstrated that the use of BIM in a project can improve the integration level of its project team. Their research aim was to investigate the US public owners' attitudes regarding correlations between aspects of IPD and information and communication technology such as BIM. The results revealed that the owners believe that information and communication technology has a positive effect on project integration and the overall performance of IPD (Azhar et al., 2014).

In summary, a positive relationship could exist between project integration and the implementation of BIM in projects. On one hand, information sharing serves as a platform or mid-point that connects project integration and MBE implementation. That is, a higher level of project integration can lead to a higher level of information sharing and, thus, provide more opportunities for MBE implementation in projects. On the other hand, MBE as a part of BIM has also been proved to be able to foster and facilitate project integration, thereby enhancing the overall project performance. The pragmatic essence of this integrated process is depicted in Figure 2.16:

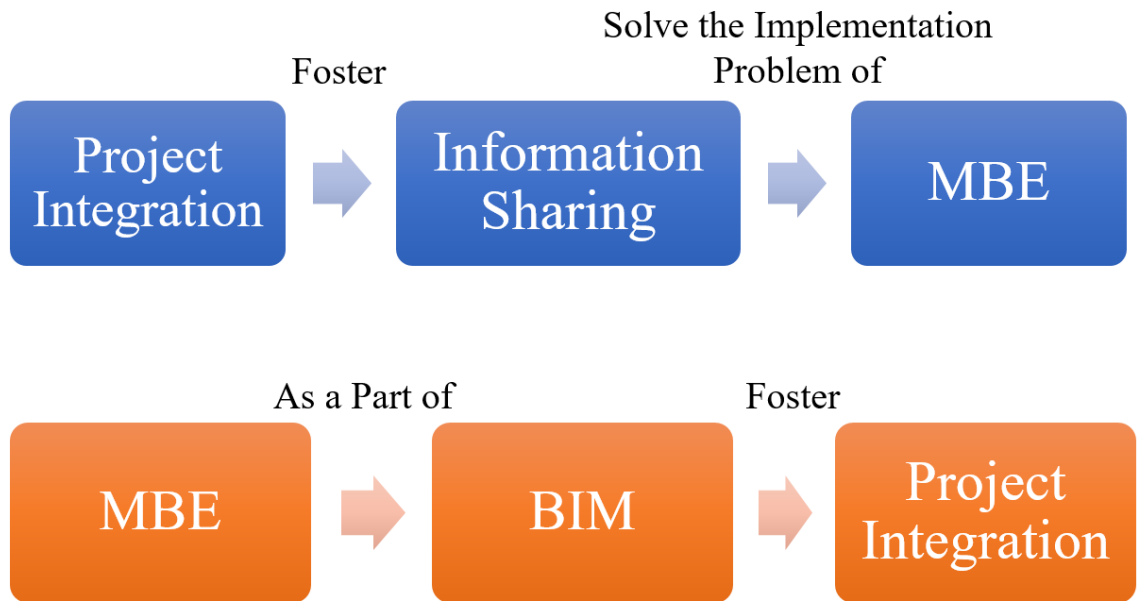


Figure 2.16. Relationship between Project Integration and MBE.

The author posits that since project integration and MBE implementation can be positively correlated; project integration could promote more opportunities for MBE implementation. Project integration could also improve MBE to a higher level of implementation, which means implementing it more efficiently; employing it more frequently; and/or applying it to more building systems and trades. These are the hypotheses the author intends to test in this thesis.

Since project integration and IPD are identified as key factors that promote the implementation of MBE in projects; the author will mainly focus on clarifying these two concepts in the following sections.

### 2.3 PROJECT INTEGRATION

When discussing IPD, Azhar et al. (2014) provided a precise definition of project integration, describing it as key project stakeholders, such as the owner, design team, general contractor, and main trades collaborating during the preconstruction phase to develop and validate various goals for the success of the project (Azhar et al., 2014).

Molenaar et al. (2014) asserted that project integration is to bring teams together. It measures the degree of compatibility between the design and construction team members, who were consolidated for a common project goal (Molenaar et al., 2014).

Similarly, according to Ospina-Alvarado et al. (2016), project integration is the opposite of fragmentation, which is quite normal in the traditional contracting structure. Moreover, project integration is initiated through a contractual agreement that can help align the goals of major project players and, as a result, tends to foster and promote collaboration among project participants (Ospina-Alvarado et al., 2016).

Although there may not be a clear definition of project integration agreed by the entire industry, the term 'project integration' is still widely used. The author hereby attempts to summarize the definition of project integration, based on the literature review: the major project participants agree on the contract stipulations of sharing risk and aligning goals during the early project phase, and collaboratively make contributions to the decision-making process. In the process, the project's main participants would share information and actively communicate with each other, so as to move forward together and add value to the project as a collective body.

As mentioned earlier, the contract constitutes the main factor that has an impact on project integration. Delving deeper into different contract types, which essentially act as a primary element of the project delivery method, the author will focus more on the project delivery method in the following sections. An exploration will also be made on the process related to the projected delivery method of IPD that has a high level of project integration.

## 2.4 PROJECT DELIVERY METHOD

To define different project delivery methods, Kenig (2011) stated that there are two defining characteristics that distinguish one delivery method from another:

- (1) How are primary construction participants linked together through contractual agreement? Does the general contractor and design team have separate agreements with the owner? Or do they have one combined contract with the owner?
- (2) Is the cost of construction one of the criteria in the selection of the general contractor?

Delivery methods widely utilized today are design-bid-build (DBB), construction management at risk (CM at-risk), design-build (DB), and IPD. Therefore, based on the defining characteristics mentioned earlier, these delivery methods can be defined as follows:

DBB is a method of project delivery in which the owner first signs a contract with a design company and then waits until the design process is finalized. Next, the owner will invite general contractors to bid, based on the completed design. Then the general contractors will bid according to the estimated prices for the entire scope of work that is required and specified in the project. Then, the owner will use a competitive procurement process to select one general contractor to build the project. The most ideal selection methodology will be either low bid or best value: total cost (Kenig, 2011). In short, the defining characteristics of DBB are as follows:

- (1) The design team and the general contractor have separate contracts with the owner.
- (2) Cost is a factor in the selection criteria of the general contractor.

CM at-risk is a relatively new project delivery system as compared to DBB; the owner in this delivery method has separate contracts with the CM at-risk company and the design team. The CM at-risk company is on board even from the early design phase of the project and is typically responsible for preconstruction services. In the process, the general contractor will collaborate with the design team, provide advice relative to the design, and ensure that the design is constructible or feasible. Then, during the construction phase, the CM at-risk company will serve as a general contractor, retain the trade contracts, and take responsibility for the performance of the work (Kenig, 2011). The major features of CM at-risk are as follows:

- (1) The design team and the general contractor have separate contracts with the owner.
- (2) Cost is not necessarily a factor in the selection criteria of the general contractor.

Furthermore, DB represents a method of project delivery in which one firm takes full responsibility for both the design and construction of a project (Kenig, 2011). The important characteristics of DB are as follows:

- (1) Design and construction are combined contractually. The owner will sign a single contract with the design-builder.
- (2) Cost is not necessarily a factor in the selection criteria of the general contractor.

IPD is a recently-developed project delivery where the owner, design team, general contractor, and other related parties sign a single multi-party agreement. This new form of project delivery method is known to lead to a higher level of collaboration among the project's participants, which is believed to produce better results than projects utilizing a traditional project delivery method (Kenig, 2011). The major qualities of IPD are as follows:

(1) The design team, general contractor, and owner (perhaps, other parties or trades) sign a multi-party agreement.

(2) Cost is not necessarily a factor in the selection criteria of the general contractor.

In summary, it can be observed from the literature review and project experiences that:

(1) The project's primary players, namely, the design team and the general contractor are organized in diverse ways within different delivery systems.

(2) The design team and the general contractor are indeed better integrated in some project delivery systems than other systems.

Although an effective project delivery method constitutes an extremely crucial and essential factor in project integration, the author believes each project is unique, and should be considered on a case by case basis in terms of the integration level. In fact, project integration can be affected by numerous factors other than the project delivery method. Those other factors, which is believed by the author to also have an impact on project integration, will be discussed in more detail in the following sections.

## 2.5 PROJECT CHARACTERISTICS THAT HAVE POTENTIAL TO IMPACT MBE IMPLEMENTATION

### 2.5.1 *Project Type*

The construction projects can be classified into: building construction, infrastructure construction (heavy civil), and industrial construction, based on the nature of construction (Chitkara, 1998). Building construction can further be broken down as residential building construction, commercial building construction, and institutional building construction (Halpin, 2010).

The author posits that construction structures and building components are essentially different in each project type and as a result, the MBE could be implemented in a different manner based on each project type. For instance, in a heavy civil project, the project team would prefer to use either a traditional estimation method over MBE, or just to employ BIM as a visualization tool. The reason behind is that most of the building structure in the heavy civil project can be perfectly sketched and presented in a 2D format, in some case, it is not necessary to put extra efforts on MBE implementation.

### 2.5.2 *Budget Level*

The construction projects are various in organizational and technological complexity, and one of the factors related to project complexity is relative project size (Safa et al., 2015). In this context, the author posits that the relative project size can be presented in terms of project budget. Thus, construction projects can be classified into: large-, small-, and middle-sized projects.

Moreover, the author posits that a larger project may be more motivated to implement MBE, since it has a more adequate budget and more complicated estimation, so that MBE, as a time-saving tool, can be more implemented to better support the project.

### 2.5.3 *Owner Type*

Public and private projects are facing different challenges and are various in typical way of management and coordination, administration, and communication (Eik-Andresen et al., 2016). The author posits that the integration level could be different based on different owner type and such difference could have impact on MBE implementation.

## 2.6 PROJECT INTEGRATION FACTORS

As asserted in Section 2.4, the project delivery method is critical to project integration and other factors (such as project type, budget level, and owner type) are also believed to have influence on project integration. However, their effect on project integration is not clear and they could not truly measure the degree of project integration, since each project is different and should be approached on a case-by-case basis. Thus, many studies have been developed to quantify the integration of the project.

Ibrahim et al. (2014) attempted to measure the level of project integration with an alliance team integration performance index, which was based on seven indicators: team leadership; trust and respect; an aligned objective on which the whole project team could focus; collective understanding; commitment from the project alliance board; the creation of a single and collocated alliance team; and free-flow communication (Ibrahim et al., 2014).

Moreover, Harper et al. (2016) designed a relational contracting norms measure method that can quantify the level of integration of construction projects. They emphasized the impact of the contract on project integration and discussed it in a systematic manner, which primarily highlighted that contracts can affect project integrations and what characteristics a contract should possess in order to foster viable integration into the project (Harper et al., 2016). They postulated that a contract that had the ability to foster project integration should contain the following characteristics: integrity; reciprocity; flexibility; propriety of means; reliance and expectation; restraint of power; contractual solidarity; and harmonization of conflict. Those characteristics comprise the eight main factors that should be taken into consideration when measuring project integration.

Ospina-Alvarado et al.'s (2016) research on a unified framework for construction project integration, proffered that the framework is able to define the key attributes of a successful project integration, along with the importance level of those factors. After analyzing the survey, 19 out of the 45 attributes were selected as critical attributes that contributed to project integration (Ospina-Alvarado et al., 2016).

While investigating a correlation between project performance and project integration, Molenaar et al. (2014) ascertained that BIM usage and planning, design charrettes, joint goal-setting, co-location, offsite prefabrication, timeliness of communication, commitment to project goals, team chemistry, frequency of compromise, and formality of communication represent the primary factors to quantify project integration (Molenaar et al., 2014).

A number of IPD studies conducted by AIA also identified project integration factors. For example, the followings were regarded as principles of IPD that support project integration in AIA's Integrated Project Delivery: A Guide (2007a): mutual respect and trust; mutual benefits and reward; collaborative innovation and decision-making; early involvement of key participants; early goal definition; intensified planning; open communication; appropriate technology organization; and leadership (AIA, 2007a).

In AIA's Integrated Project Delivery: A Working Definition (2007b), IPD principles are also discussed, which view nine principles as critical factors to consider. These include mutual respect, mutual benefit, early goal definition, clearly defined open standards, appropriate technology, a high-performance team, and leadership (AIA, 2007b).

More recently, in AIA (2011), another principle was identified after five cases were studied, namely, IPD makers that could also be viewed as project integration indexes. The IPD makers include relational contracts; protection from litigation; aligned project goals; informed and

balanced decision-making; open communication; risks that are identified and accepted early; multi-party agreements; a team that is design-intensive and budget-intensive; early contribution of expertise; pre-existing relationships between parties; leadership; shredding financial risk and rewards based on project outcome; liability waivers between key participants; fiscal transparency between key participants; BIM; implementing lean construction processes; and co-location (AIA, 2011).

Thomsen et al. (2009) also discussed project integration issues in their IPD report. They not only focused on the IPD principles mentioned above, but also conducted an in-depth study on how recently developed technology such as BIM and lean principles can impact project integration (Thomsen et al., 2009).

After discussing three aspects of IPD requirement: contractual requirements, technological requirements, and cultural requirements, Lee et al. (2013) proffered that IPD requires project participants to share risks and rewards, to team up early, and to be collaborative in the early design decision-making process. IPD further requires the usage of technology like BIM and other project management information systems (PMIS) that can support the entire process (Lee et al., 2013). Finally, IPD requires organizational and cultural improvements, where trust, leadership, and open communication are emphasized in the daily working process.

Table 2.2 summarizes all the factors mentioned by the above literature.

Table 2.2. Project Integration Factors

	Ibrahim et al. (2014)	Harper et al. (2016)	Ospina-Alvarado et al. (2016)	Molennar et al. (2014)	AIA (2007a)	AIA (2007b)	AIA (2011)	Thomsen et al. (2009)	Lee et al. (2013)
Project Team Involvement Period			x	x	x	x	x	x	x
Project Team Selection Criteria			x						
Communication	x		x	x	x	x	x	x	x
Coordination			x						x
Information Sharing			x						x
Trust and Respect	x		x		x	x		x	x
Leadership	x		x		x	x		x	x
Intensified Planning Phase			x		x				
Team Structure and Responsibilities			x	x				x	x
Data Structure						x			
Early-defined Goal			x	x	x	x			
Aligned Goal	x		x	x	x	x	x	x	x
Contract		x	x				x	x	x
Top Management Support	x		x						
Resources			x	x	x	x		x	x

## Chapter 3. RESEARCH METHOD

### 3.1 Survey

The main objective of this research is to test the hypotheses that project integration has a positive impact on the MBE implementation indexes and to find out other effective factors. In order to achieve the objective, the surveying method was employed in this study to collect opinions from practitioners in the construction industry. The results of the survey were analyzed statistically, and were used to prove to existence of a correlated relationship between project integration and the implementation level of MBE, as well as to figure out the MBE implementation effective factors.

In this research, the Catalyst WebQ tool provided by the University of Washington was utilized, since it can be used to design or construct surveys and it offers an effective distribution method by sending links via email or LinkedIn with a survey invitation. This study mainly focused on garnering responses from estimators and BIM/VDC operators from the general contractor side. These individuals are most likely to possess advanced knowledge of MBE and further have the ability to attain a deeper insight on how MBE is constructed in their project. The first invitation emails were sent in March 2017, and the survey opened for 24 weeks (until September 2017) to receive feedback.

The questions in the survey were developed mainly based on the literature review and the author's previous experience with MBE tools. Furthermore, the preliminary version of the survey was tested by seven individuals who offered constructive advice on the survey's structure and questions, which was used to developed the final version. The final version was divided into

three parts: Part 1 requires the respondents' basic project information; Part 2 asks the survey participants to identify the levels of MBE implementation in their current project; and Part 3 prompts the survey participants to score the project integration level of their project. The survey will be included in the Appendix A.

### 3.2 Interview

After analyzing the data collected from the survey, the author also conducted interviews with three individuals who have significant experience in MBE. By doing so, it provided a more comprehensive picture of MBE implementation in the construction industry and helped the author to explain and interpret the survey results in a more accurate manner.

The interview questions were also developed based on both the literature review and the author's previous experience with MBE tools. The questions about the following six aspects were asked during the interviews:

- (1) How is MBE implemented in the project?
- (2) The interviewee's opinion on the relationship between project integration and MBE implementation.
- (3) The challenges faced by the construction industry to effectively implement MBE in current projects.
- (4) The interviewee's opinion on the most efficient method to improve the implementation levels of MBE.
- (5) The interviewee's opinion on the consequences brought about by MBE implementation.
- (6) The reason why the interviewee opted to implement MBE.

## Chapter 4. SURVEY DEVELOPMENT/ DATA COLLECTION

### 4.1 SURVEY DEVELOPMENT

#### 4.1.1 *Model-based Estimation*

According to the hypotheses of this thesis, the survey included questions about the efficiency of MBE, frequency of MBE, and the percentage of the estimation done by MBE.

##### (1) Efficiency of MBE

The author believes that the utilization of BIM in estimation can profoundly enhance the efficiency of estimation. Moreover, BIM models, as a visualization tool, could assist the estimator in developing a better understanding relative to the project, so the first level of efficiency should be BIM as a visualization tool. A survey question was developed to query participants if they would use BIM in their project. If the answer was yes, then the efficiency level was established at level 1 at least.

According to the results of the literature review, there is a common workflow that MBE would typically follow:

- (a) Categorize the model based on the location and type of each building element.
- (b) Include the quantities of the element into a construction division system.
- (c) Set unit prices for each item.

The last two processes should be manually performed in the MBE process. Thus, for the first step of the MBE work flow, the model categorization will be mainly discussed in the thesis. First, the estimator can choose to either categorize the model elements manually or automatically. The categorization of model elements is conducted manually with MBE tools such as Navisworks in some cases, where the quality of the model is not sufficiently adequate.

However, it could also be performed automatically in tools other than Navisworks in cases where the model quality is sound. By performing this step automatically, it can most certainly improve the efficiency of estimating process. Thus, a question was posed in the survey to garner information about whether this step is typically done manually or automatically. Second, some general contractors prefer building their own models to support the MBE process; however, models built by the general contractor are not considered as efficient as obtaining a model directly from the design team. Hence, another question was asked to determine if the general contractor uses their own model for MBE.

These two questions can collectively identify the level of efficiency relative to MBE, and the logic behind this is illustrated in Figure 4.1:

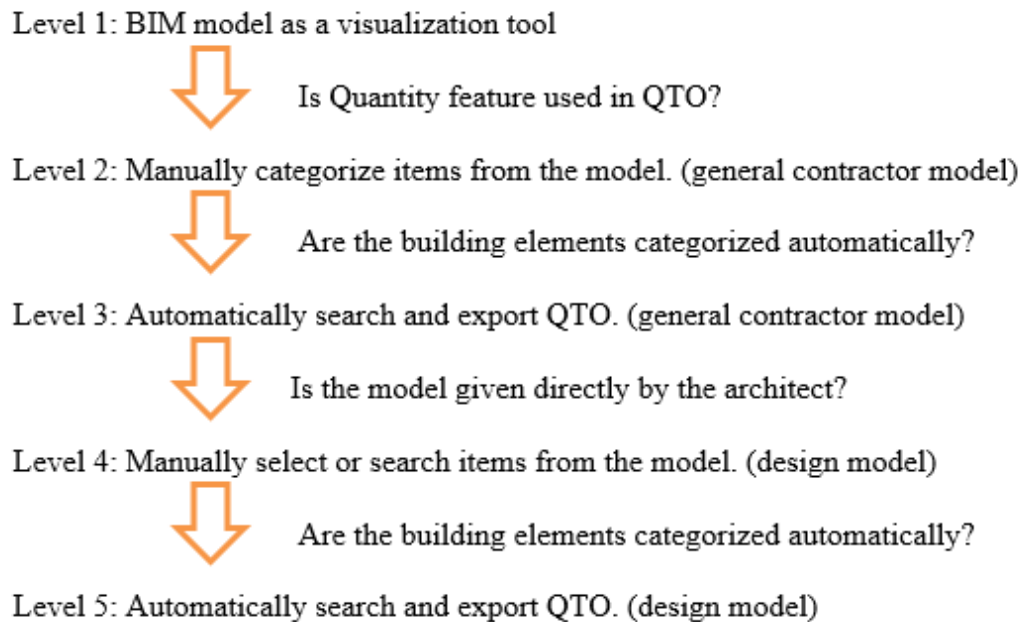


Figure 4.1. Efficiency Level of MBE.

(2) Frequency of MBE

To identify the frequency of MBE, the survey directly asked participants how often (as in how many weeks) they would be engaged with MBE. The lower the number, the more frequently the project would be in using MBE.

### (3) Percentage of MBE

Survey participants were asked about what percentage of estimation is normally performed with the support of MBE tools. The question was to identify how much MBE is actually used in the project. The larger the number, the more trades and sections of the project are calculated based on MBE.

#### 4.1.2 *Project Integration*

Project integration was quantified utilizing all the project integration factors that were identified in the literature review with an equal weight. Survey participants were asked to score their project integration based on factors from 1 to 5, where 5 = “strongly agree” and 1 = “strongly disagree”. Table 4.3 presents the description of each factor.

Table 4.3. Description of Project Integration Factors

Project Integration Factors	Description
Communication	Open and direct communication is maintained between all project team members
Coordination	All participants are coordinated in a way that conflicts are avoided
Information Sharing	Information sharing is on-time and adequate
Trust and Respect	Trust and respect are shown in work environment
Leadership	Team members show good leadership skills
Intensified Planning Phase	Planning phase is intensified in the project.
Team Structure and Responsibilities	Team structure is defined up front, and the responsibilities of each person are clearly stated
Data Structure	Data of the project is exchanged, with a disciplined and transparent data structure.
Early-defined Goal	Project goals and objectives are defined in the early phase
Aligned Goal	Project goals, stakeholders' goals, and individual's goals are aligned in the project
Contract	Contract in this project fosters collaboration of the entire team
Top Management Support	Top management team believes the collaboration can bring better project results
Resources	Resources in terms of knowledge, technology, and specific skills are available in supporting the collaboration of the team

In addition to the factors in Table 4.3, the survey included questions about the project team involvement period and the project team selection criteria in the form of multiple choice questions. Both items had four choices. For the project team involvement period factor, participants could choose from pre-design, schematic design, design development, and the

construction document. Concerning the project team selection criteria factor, participants were suggested to select from low bid, best value, cost, best value, fee, and qualification based selection.

#### 4.1.3 *Other Factors*

The survey also included four additional factors that may have a relationship with the MBE indexes: project delivery method, project type, project budget level, and owner type.

The participant can choose from four project delivery methods that are defined in Section 2.4: DBB, CM at risk, DB, and IPD. The project delivery methods can have impact on MBE implementation, because the project participants collaborate differently in different project delivery methods.

The project type in this research was categorized into commercial, industrial, institutional, residential, and heavy civil. The project type was included in the survey, because the projects with diverse project types can be different in operation and marketing, which may have an influence on the project's MBE implementation.

Similarly, the project budget level was categorized into large-, small-, and middle-sized projects. If the budget was larger than \$50,000,000, then the author categorized it as a large project, while the budget less than \$5,000,000 was classified as a small project. The remainder with budgets between \$5,000,000 and \$50,000,000 was categorized as a middle-sized project. The author assumed that a larger project may have more leverage to implement MBE, since it can allocate more budget to support MBE. Additionally, the project may be more complicated in estimation, so that the use of MBE is more justified as a time-saving tool.

The owner type of projects can be either be publicly- or privately-owned. The difference in the project owner's type may have an effect on the MBE indexes, since the role and intention of the owner may be different.

## 4.2 DATA COLLECTION

By the end of September 2017, 31 survey responses were received from eight estimators, twelve BIM operators, eight project engineers, one project manager, and others. Figure 4.2 summarizes the basic information of the responses.

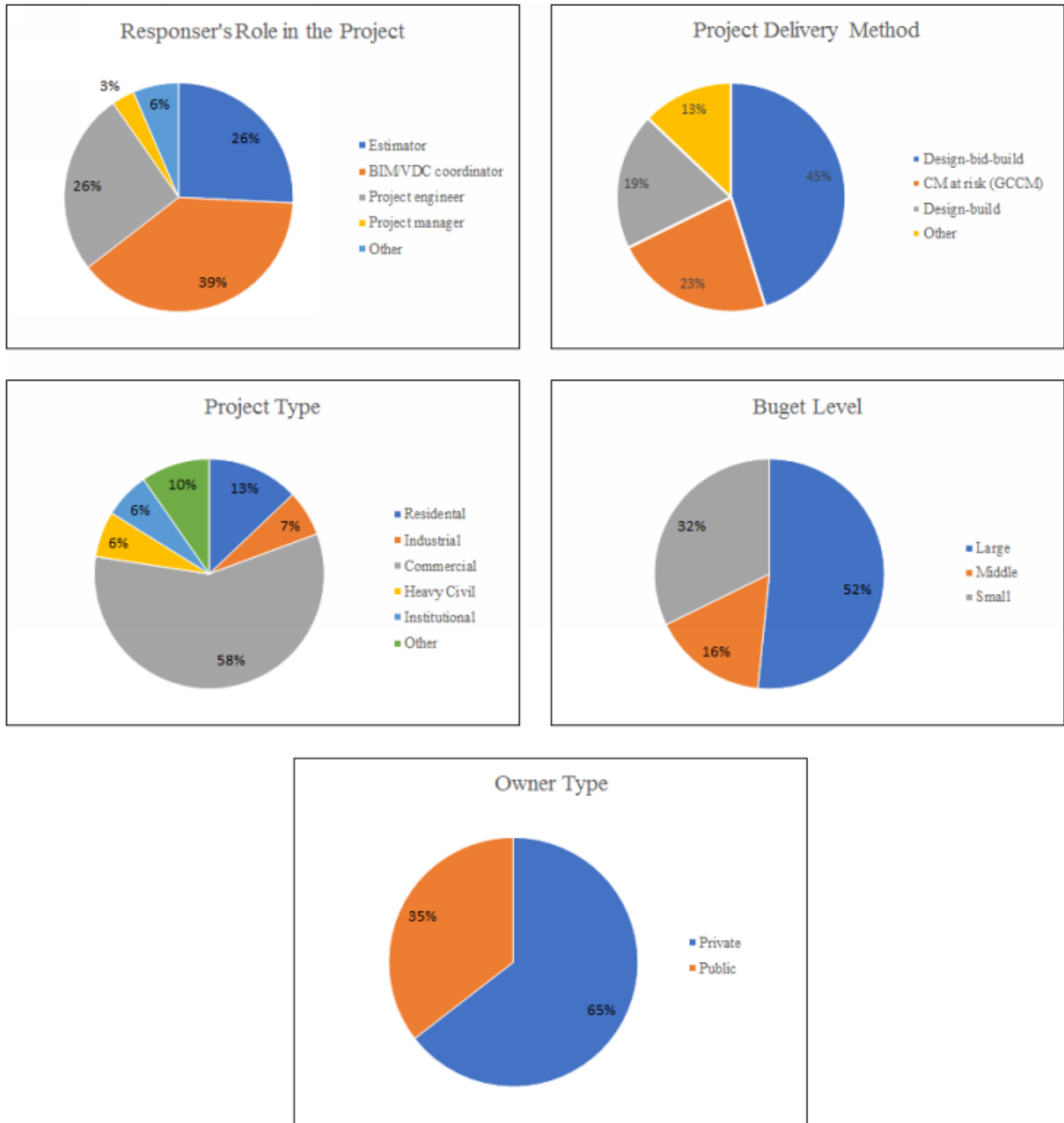


Figure 4.2. Basic Information of Survey Responses.

In terms of project delivery method, there were fourteen DBB, seven CM at risk, six DB and four other projects. The responses were from four residential projects, two industrial projects, two institutional projects, two heavy civil projects, and eighteen commercial projects. There were three projects that were somewhat challenging to define in terms of project type; thus, the

author categorized them as “other project type”. The total amount of the projects ranged from \$58,000 to \$30 billion that were categorized into small, medium, and large projects based on the pre-determined budget levels. As a result, there were fifteen large projects, five medium projects, and ten small projects. In terms of owner type, the responses were from twenty private projects and eleven public projects.

The following chapter will provide a more comprehensive and in-depth analysis of the received responses.

## Chapter 5. DATA ANALYSIS AND RESULT

The survey was developed online and the link to the survey was distributed via various methods, including emails and LinkedIn. A paper-based survey was also distributed at the same time, in an attempt to collect more responses. As a result, 31 responses were received. After an initial review of the collected data, the author decided to eliminate nine samples, because they were at Level 0 of the MBE efficiency level, which implied that those participants do not use BIM in their projects. Thus, the total number of valid samples used for the analysis was 22 out of 31, establishing the valid rate at 70.97%.

The main purpose of the survey is to gain a deeper insight into the correlation between project integration and MBE efficiency, MBE frequency, and the percentage of MBE implementation in the total budget. In that regard, the project integration factors represent dependent variables, while MBE implementation indexes are independent variables. The survey included thirteen project integration factors. A 1 to 5 Likert scale (5 = “strongly agree” and 1 = “strongly disagree”) was employed to quantify the thirteen factors: communication; coordination; information sharing; trust and respect; leadership; intensified planning; team structure and responsibilities; data structure; early-defined goal and objectives; aligned goals; contract; top management team; and resources. Since the Likert scale is used, those factors represent numeric variables.

The survey also included other two questions that were related to the project integration: project team involvement time and selection criteria. Those questions were asked in the form of multiple-choice questions, which distinguish these factors as categorical variables. The author also analyzed the relationship between basic project information (project types, project budget levels, owner types and project delivery methods) and MBE indexes (MBE efficiency, MBE frequency, and the percentage of MBE implementation in the total budget amount). The basic project

information questions were also categorical variables, because they were asked in the form of multiple-choice questions.

For the numeric variables, the author first conducted a Pearson correlation coefficient analysis, so as to verify if any correlation exists between the independent variables and the dependent variables. Moreover, if the correlation was proven to exist, a regression model was developed. For the categorical variables, the author conducted a one-way ANOVA analysis to verify if there is a significant difference in the MBE indexes between the diverse categories.

### 5.1 PEARSON CORRELATION COEFFICIENT ANALYSIS

A Pearson correlation coefficient analysis was used to test the hypotheses that positive correlation relationships exist between individual project integration factors and MBE indexes. Each hypothesis is listed in Tables 5.4 through 5.6.

Table 5.4 Hypotheses: Positive Correlation between Project Integration and MBE Efficiency

Hypothesis	Independent Variable	Dependent Variable
H1.1	The more open and direct communication is maintained between all project team members	The higher the MBE efficiency levels will be in the project
H1.2	The better the project is coordinated	
H1.3	The more adequate and timely the information is shared	
H1.4	The more trust and respect that is shown in the work environment	
H1.5	The better leadership skills the team members have	
H1.6	The more intensified the planning phase is	
H1.7	The clearer the team structure is defined up front	
H1.8	The better the data exchange structure is	
H1.9	The earlier the project's goals and objectives are defined	
H1.10	The more the project's goals, stakeholders' goals, and individual's goals are aligned in the project	
H1.11	The more the contract fosters collaboration with the entire team	
H1.12	The more the top management team believes in the effectiveness of collaboration	
H1.13	The more resources in terms of knowledge, technology, and specific skills are available in supporting the collaboration of the team	

Table 5.5 Hypotheses: Positive Correlation between Project Integration and MBE Frequency

Hypothesis	Independent Variable	Dependent Variable
H2.1	The more open and direct communication is maintained between all project team members	The higher the MBE frequency levels will be in the project
H2.2	The better the project is coordinated	
H2.3	The more adequate and timely the information is shared	
H2.4	The more trust and respect that is shown in the work environment	
H2.5	The better leadership skills the team members have	
H2.6	The more intensified the planning phase is	
H2.7	The clearer the team structure is defined up front	
H2.8	The better the data exchange structure is	
H2.9	The earlier the project's goals and objectives are defined	
H2.10	The more the project's goals, stakeholders' goals, and individual's goals are aligned in the project	
H2.11	The more the contract fosters collaboration with the entire team	
H2.12	The more the top management team believes in the effectiveness of collaboration	
H2.13	The more resources in terms of knowledge, technology, and specific skills are available in supporting the collaboration of the team	

Table 5.6 Hypotheses: Positive Correlation between Project Integration and MBE Percentage

Hypothesis	Independent Variable	Dependent Variable
H3.1	The more open and direct communication is maintained between all project team members	The higher the MBE percentag levels will be in the project
H3.2	The better the project is coordinated	
H3.3	The more adequate and timely the information is shared	
H3.4	The more trust and respect that is shown in the work environment	
H3.5	The better leadership skills the team members have	
H3.6	The more intensified the planning phase is	
H3.7	The clearer the team structure is defined up front	
H3.8	The better the data exchange structure is	
H3.9	The earlier the project's goals and objectives are defined	
H3.10	The more the project's goals, stakeholders' goals, and individual's goals are aligned in the project	
H3.11	The more the contract fosters collaboration with the entire team	
H3.12	The more the top management team believes in the effectiveness of collaboration	
H3.13	The more resources in terms of knowledge, technology, and specific skills are available in supporting the collaboration of the team	

The Pearson correlation coefficient determination criteria (denoted by R) used in this research is as follows:

- $0.8 < | R | \leq 1$  represents a very strong correlation

- $0.6 < | R | \leq 0.8$  depicts a strong correlation
- $0.4 < | R | \leq 0.6$  is a moderate correlation
- $0.2 < | R | \leq 0.4$  represents a weak correlation
- $0 < | R | \leq 0.2$  constitutes a very weak correlation
- $| R | = 0$  is uncorrelated

The confidence interval in this research is set at 95%, meaning that when the p-value is lower than 0.05, the result is statistically meaningful.

#### 5.1.1 *Pearson Correlation Coefficient Analysis of MBE Efficiency with All Project Integration Factors*

The Pearson correlation coefficient result is depicted in Table 5.7, indicating that all the hypotheses were not statistically meaningful except for H1.3. This indicates that information sharing is correlated with the MBE efficiency level ( $P=0.017 < 0.05$ ;  $R=-0.502$ ), which means that information sharing has a negative and moderate relative relationship with the MBE efficiency level. The research intends to prove the project integration factors to have positive correlation with MBE indexes. However, the result revealed that information sharing has a negative and moderate correlation with the MBE efficiency level.

Table 5.7. MBE Efficiency Pearson Correlation Coefficient

<b>MBE Efficiency Pearson Correlation Coefficient</b>			
	Pearson Correlation	Sig. (2-tailed)	N
Communication	-.129	.568	22
Coordination	.277	.211	22
Information Sharing	-.502*	.017	22
Trust and Respect	-.226	.312	22
Leadership	-.234	.294	22
Intensified Planning Phase	-.214	.338	22
Team Structure and Responsibilities	.221	.324	22
Data Structure	-.224	.316	22
Early-defined Goal	-.223	.318	22
Aligned Goal	-.104	.646	22
Contract	.166	.462	22
Top Management Support	-.012	.959	22
Resources	-.282	.204	22
*. Correlation is significant at the 0.05 level (2-tailed).			
**. Correlation is significant at the 0.01 level (2-tailed).			

5.1.2 *Pearson Correlation Coefficient Analysis of the MBE Frequency with All Project Integration Factors*

The Pearson correlation coefficient results are presented in Table 5.8. All the hypotheses were not statistically meaningful except for H2.3, H2.8, H2.10, and H2.13, which indicates that:

- (1) Information sharing is correlated with the MBE frequency ( $P=0.038<0.05$ ) with the correlation coefficient  $R=-0.445$ . It means that information sharing exhibits a positive and moderate correlation with the MBE frequency.
- (2) Data structure is correlated with the MBE frequency ( $P=0.002<0.05$ ) with the correlation coefficient  $R=-0.614$ . It indicates that the data structure has a positive, strong correlation with the MBE frequency.

- (3) Aligned goals are correlated with the MBE frequency ( $P=0.014<0.05$ ) with the correlation coefficient  $R=-0.516$ . It depicts that the aligned goal factor has a positive and moderate correlation with the MBE frequency.
- (4) Resources are correlated with the MBE frequency ( $P=0.009<0.05$ ) with the correlation coefficient  $R=-0.546$ . It indicates that the resource factor has a positive and moderate correlation with the MBE frequency.

Table 5.8. MBE Frequency Pearson Correlation Coefficient

<b>MBE Frequency Pearson Correlation Coefficient</b>			
	Pearson Correlation	Sig. (2-tailed)	N
Communication	-.100	.657	22
Coordination	.130	.564	22
Information Sharing	-.445*	.038	22
Trust and Respect	-.110	.625	22
Leadership	-.343	.118	22
Intensified Planning Phase	-.220	.325	22
Team Structure and Responsibilities	-.114	.613	22
Data Structure	-.614**	.002	22
Early-defined Goal	-.161	.475	22
Aligned Goal	-.516*	.014	22
Contract	.045	.844	22
Top Management Support	-.007	.976	22
Resources	-.546**	.009	22
*. Correlation is significant at the 0.05 level (2-tailed).			
**. Correlation is significant at the 0.01 level (2-tailed).			

Since multiple factors appeared to be correlated with MBE Frequency, a regression model between the four project integration factors and the MBE frequency was developed and will be presented in Section 5.2.

### 5.1.3 *Pearson Correlation Coefficient Analysis of MBE Implementation Percentage with All Project Integration Factors*

The Pearson correlation coefficient results shown in Table 5.9, indicating the p-values > 0.05 for all the factors; thus, hypotheses H3.1 to H3.13 are not statistically meaningful.

Table 5.9. MBE Percentage Pearson Correlation Coefficient

<b>MBE Percentage Pearson Correlation Coefficient</b>			
	Pearson Correlation	Sig. (2-tailed)	N
Communication	.088	.696	22
Coordination	.082	.716	22
Information Sharing	.049	.828	22
Trust and Respect	.107	.636	22
Leadership	.143	.526	22
Intensified Planning Phase	.051	.822	22
Team Structure and Responsibilities	.151	.503	22
Data Structure	.216	.334	22
Early-defined Goal	.157	.486	22
Aligned Goal	.235	.293	22
Contract	-.064	.777	22
Top Management Support	-.150	.504	22
Resources	.127	.573	22
*. Correlation is significant at the 0.05 level (2-tailed).			
**. Correlation is significant at the 0.01 level (2-tailed).			

## 5.2 REGRESSION ANALYSIS

In Section 5.1.2, the MBE frequency was found to be correlated with information sharing, data structure, aligned goals and resources. The negative correlation coefficients of those factors demonstrate that a positive correlation exists between the project integration and the MBE frequency for the selected factors individually. The analysis results imply that in order to implement MBE more frequently in a project, the project team is suggested to improve information

sharing, and to have a better data structure, aligned goals and enough resources to support team collaboration. The results also provide ideas to the industry regarding methods to increase the frequency of MBE, so that they could garner more beneficial results from MBE.

In this section, the author further studied these factors to determine the most critical factors that affect MBE frequency. Therefore, an “enter” regression method will be used in this case firstly. The multiple correlation coefficient R indicates the correlation between the predicted variable value that is calculated by the model and the actual variable value. The larger the R value, the better the model is developed. The coefficient of determination ( $R^2$ ) indicates the percentage of the variable value that can be explained by the model. The larger the  $R^2$  value, the more the variable value can be explained by the model.

Table 5.10 shows that the model has  $R=0.668$ , which indicates that the model is acceptable, while  $R^2=0.446$ , meaning that the model can clarify and explain 44.6% of the dependent variable.

Table 5.10. MBE Frequency Regression Model Summary (Enter Method)

<b>Model Summary</b>				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.668 <sup>a</sup>	.446	.316	5.74579

a. Predictors: (Constant), Resources, Information\_Sharing, Data\_Structure, Aligned\_Goal

The developed regression model is expressed in Equation 5.1 and Table 11:

$$y = -1.908x_1 - 5.544x_2 + 1.507x_3 - 0.724x_4 \tag{5.1}$$

where  $y$  = the MBE frequency,  $x_1$  = the information sharing factor,  $x_2$  = the data structure factor,  $x_3$  = the aligned goal factor, and  $x_4$  = the resource factor.

Table 5.11. MBE Frequency Regression Model Coefficients (Enter Method)

		Coefficients <sup>a</sup>				
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	25.618	6.015		4.259	.001
	Information Sharing	-1.908	1.828	-.272	-1.043	.311
	Data Structure	-5.544	2.785	-.618	-1.990	.063
	Aligned Goal	1.507	2.942	.221	.512	.615
	Resources	-.724	2.875	-.111	-.252	.804

a. Dependent Variable: Frequency

However, the p-values of the factors in the regression model are 0.311, 0.063, 0.615, and 0.804 (Table 5.11), all of them are higher than 0.05. This can be caused by the correlation relationship between the four factors: information sharing, data structure, aligned goal, and resources. Although the model developed by the enter method can be used to predict the MBE frequency in a relatively high accuracy, the author decided to further analyze to find the effective factors by using “stepwise” method. Table 5.12 and Table 5.13 indicates that all the integration factors are excluded in the process of analysis except the data structure factor. Thus, the data structure is the only effective factor to the MBE frequency, and the model can explain 37.6% of the dependent variable, which is acceptable value in social science.

Table 5.12. MBE Frequency Regression Model Summary (Stepwise Method)

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.614 <sup>a</sup>	.376	.345	5.62245

a. Predictors: (Constant), Data\_Structure

Table 5.13. MBE Frequency Regression Model Coefficients (Stepwise Method)

		Coefficients <sup>a</sup>				
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	22.040	5.112		4.311	.000
	Data_Structure	-5.505	1.585	-.614	-3.475	.002

a. Dependent Variable: Frequency

The model demonstrate that a positive correlation exists between the integration factor and the MBE frequency and that the data structure is the most effective factor. The analysis results imply that in order to implement MBE more frequently in a project, the project team is suggested to put effort in improving the data structure of the project. The result also provides ideas to the industry regarding methods to increase the frequency of MBE, so that they could have a better chance to gain beneficial results from MBE and to explore more into MBE technology.

### 5.3 ANOVA ANALYSIS

The author conducted an ANOVA analysis in this section, aiming to discover if the two project integration factors (project team involvement period and selection criteria) and the four project basics (information such as project delivery method, project type, budget level, and owner type) have an effect on MBE implementation indexes (efficiency, frequency and implementation percentage). The confidence interval in this research is set at 95%, which indicates that when the p-value of a hypothesis is lower than 0.05, the result is statistically meaningful.

The p value of each ANOVA analysis is summarized in Table 5.14:

Table 5.14. ANOVA Analysis Summary

	Efficiency	Frequency	Percentage
Project Team Involvement Period	0.945	0.043	0.956
Project Team Selection Criteria	0.646	0.864	0.401
Project Delivery Method	0.081	0.016	0.026
Project Type	0.672	0.270	0.134
Budget Level	0.086	0.253	0.069
Owner Type	0.511	0.869	0.103

Table 5.14 indicates that:

- (1) There is a significant disparity in MBE frequency of the different project teams that are involved from different periods ( $P=0.043<0.05$ ).
- (2) There exists a significant difference in MBE frequency of the different project teams that are employing different delivery methods ( $P=0.016<0.05$ ).
- (3) There is a significant difference in MBE percentage values of the different project teams that are employing different delivery methods ( $P=0.026<0.05$ ).

The author further studied the primary value of MBE indexes (efficiency, frequency, and percentage) of different project team involvement periods and project delivery methods. The results will be shown in the following sections.

### 5.3.1 *ANOVA Analysis among Different Project Delivery Methods Concerning MBE Indexes*

There are significant differences in the various delivery methods' MBE frequency ( $P=0.016<0.05$ ) and percentage ( $P=0.026<0.05$ ). The average MBE frequency in case of DBB is 1.778, indicating that a DBB project appears to implement MBE more frequently than the other delivery methods. The average MBE frequency in case of CM at risk is 2.500, significantly less than the average MBE frequency value for DB (14.667) (Table 5.1). Furthermore, the average MBE percentages of DBB, CM at risk, and DB are 58.889, 33.333, and 48.333, respectively. Average MBE percentage of DBB is higher than that of DB, and much higher than that of CM at risk.

Table 5.15. ANOVA Analysis and MBE Indexes Mean Value Comparison of Different Project Delivery Methods

		N	Mean	Std. Deviation	Std. Error	F	Sig.
Efficiency	CM at risk	6	4.667	0.516	0.211	2.643	0.081
	Design-bid-build	9	2.778	1.202	0.401		
	Design-build	3	3.667	1.155	0.667		
	Other	4	3.000	2.309	1.155		
	Total	22	3.455	1.471	0.314		
Frequency	CM at risk	6	2.500	2.074	0.847	4.511	0.016
	Design-bid-build	9	1.778	1.394	0.465		
	Design-build	3	14.667	11.547	6.667		
	Other	4	7.500	9.574	4.787		
	Total	22	4.773	6.948	1.481		
Percentage	CM at risk	6	33.333	23.381	9.545	3.916	0.026
	Design-bid-build	9	58.889	29.768	9.923		
	Design-build	3	48.333	38.837	22.423		
	Other	4	5.000	10.000	5.000		
	Total	22	40.682	32.156	6.856		

### 5.3.2 ANOVA Analysis among Different Project Team Involvement Periods Concerning MBE Indexes

There is a significant difference in the MBE frequency ( $P=0.043 < 0.05$ ) within diverse project teams that are involved from different periods. The average frequency of MBE implementation in the project teams that were involved from the construction document (CD) is 0.500, which is higher in frequency than the teams that were involved during design development (DD) and pre-design (PD) (2.600 and 2.556). It is also much higher than the teams that were involved during the schematic design (SD) (11.333) (Table 5.16).

Table 5.16. ANOVA Analysis and MBE Indexes Mean Value Comparison of Different Involvement Periods

		N	Mean	Std. Deviation	Std. Error	F	Sig.
Efficiency	Construction Document	2	3.000	2.828	2.000	0.124	0.945
	Design Development	5	3.600	1.673	0.748		
	Schematic Design	6	3.667	1.633	0.667		
	Pre-design	9	3.333	1.225	0.408		
	Total	22	3.455	1.471	0.314		
Frequency	Construction Document	2	0.500	0.707	0.500	3.341	0.043
	Design Development	5	2.600	2.302	1.030		
	Schematic Design	6	11.333	10.558	4.310		
	Pre-design	9	2.556	3.005	1.002		
	Total	22	4.773	6.948	1.481		
Percentage	Construction Document	2	35.000	49.497	35.000	0.105	0.956
	Design Development	5	48.000	41.473	18.547		
	Schematic Design	6	39.167	34.988	14.284		
	Pre-design	9	38.889	27.131	9.044		
	Total	22	40.682	32.156	6.856		

## 5.4 SUMMARY

The statistically meaningful results discussed in this chapter are summarized below:

- (1) Information sharing has a negative and moderate correlation with the MBE efficiency level.
- (2) Information sharing has a positive and moderate correlation with the MBE frequency.
- (3) Data structure exhibits a positive and strong correlation with the MBE frequency and is the most effective factor to MBE frequency.
- (4) Aligned goals have a positive and moderate correlation with the MBE frequency.
- (5) Resources have a positive and moderate correlation with the MBE frequency.

- (6) There is a significant disparity in the different delivery methods for the MBE frequency. The average MBE frequency in DBB is 1.778, which is much higher than that of the other delivery methods.
- (7) There is a significant disparity in the diverse delivery methods for the MBE percentage values. The average MBE percentage for DBB is 58.889, which is substantially higher than the other delivery methods.
- (8) There is a significant variance in the different project team involvement periods for the MBE frequency. The average frequency of MBE implementation in the project team that was involved from the construction document phase is 0.500, which is much higher in frequency than the other project teams that were involved from different design periods.

In summary, the MBE frequency has a positive relationship with project integration factors, which means that better project team integration could support the team to utilize MBE more frequently in the project. The critical factors for enhancing the MBE frequency are as follows: information sharing, data structure, aligned goals, and resources. This indicates that the team that has open and adequate information sharing, a well-defined data structure, aligned project goals, and that are supported with enough resources such as knowledge, technology, and skills could use MBE more frequently. However, the ANOVA analysis results seem to provide a counterintuitive conclusion: the DBB project delivery system that is considered to have a lower project integration has a higher level of MBE frequency and MBE percentage. In addition, the teams that were involved late in the project also exhibited a high MBE frequency.

The author examined these correlations between project integration and project delivery methods, as summarized in Table 5.17, and the correlation relationship between project integration and project team involvement time, as summarized in Table 5.18.

Table 5.17. ANOVA Analysis of Different Project Delivery Method's Project Integration

Factors		
ANOVA		
	F	Sig.
Communication	0.731	0.547
Coordination	0.938	0.443
Information Sharing	0.688	0.571
Trust and Respect	0.279	0.840
Leadership	0.496	0.690
Intensified Planning Phase	0.107	0.955
Team Structure and Responsibilities	1.026	0.404
Data Structure	0.181	0.908
Early-defined Goal	0.899	0.461
Aligned Goal	0.708	0.560
Contract	1.055	0.393
Top Management Support	0.587	0.631
Resources	0.845	0.487

Table 5.18. ANOVA Analysis of Different Project Team Involvement Time's Project

Integration Factors		
ANOVA		
	F	Sig.
Communication	0.454	0.718
Coordination	1.046	0.396
Information Sharing	0.670	0.581
Trust and Respect	1.042	0.398
Leadership	1.244	0.323
Intensified Planning Phase	1.096	0.376
Team Structure and Responsibilities	1.304	0.304
Data Structure	1.295	0.307
Early-defined Goal	0.940	0.442
Aligned Goal	1.234	0.326
Contract	0.437	0.729
Top Management Support	0.642	0.598
Resources	0.498	0.688

It can also be observed that there is no significant difference between project integration and the project delivery method, as well as project involvement time, which suggests that each project is unique, and should be considered on a case-by-case basis in terms of the integration level.

On the other hand, the design is almost 100% complete in the DBB when a general contractor is involved, and the model provided by the design team is better developed, as compared to that of the other delivery methods. The same thing happens to projects when the construction team is involved late in the design process. Furthermore, in DBB, there is limited time in the bidding process, which could also create a need for MBE. That could be a reason why DBB, which is assumed to have a lower project integration, has a high level of MBE frequency and MBE percentage, as well as why the team that is involved late in the project has a high MBE frequency.

Figure 5.1 shows a scatter plot of project integration averages, given diverse MBE indexes. It can be observed that:

- (1) MBE efficiency and project integration have a trend to be positively correlated in most projects, except for three samples highlighted in Figure 5.1.
- (2) MBE frequency and project integration have a negative correlation, except for three samples highlighted in Figure 5.1.
- (3) MBE percentage does not appear to be correlated with project integration.

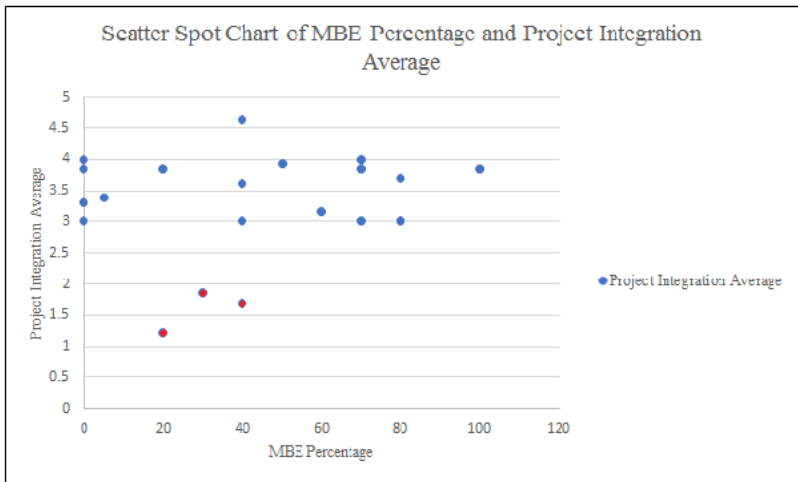
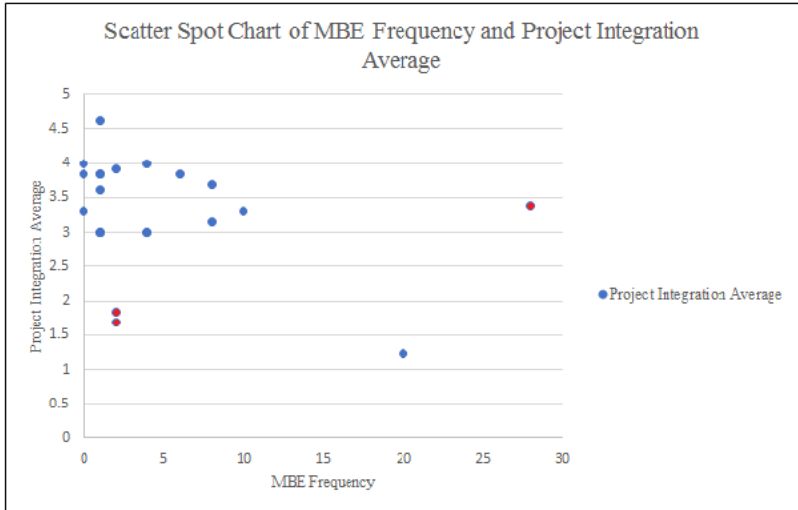
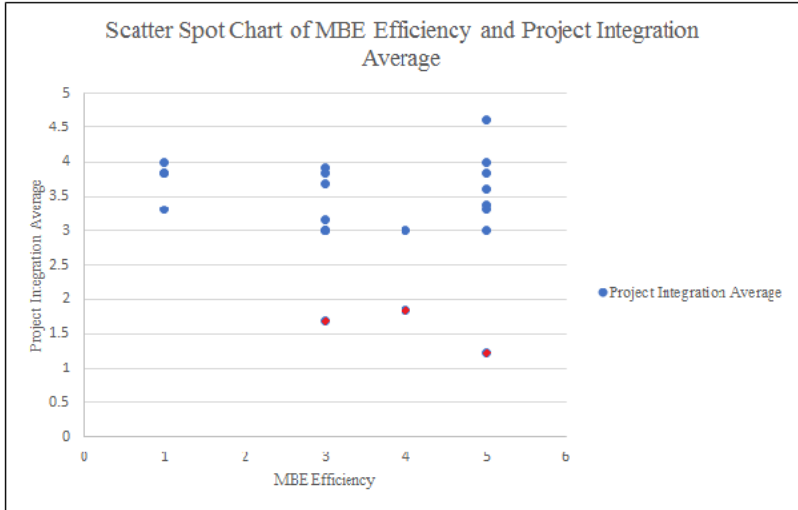


Figure 5.1. MBE Indexes Scatter Chart

The author conducted additional interviews and obtained an answer for the following findings by analyzing the interview results (Chapter 6): (1) why these three samples have negative correlations between MBE indexes and project integration, and (2) why information sharing has a negative and moderate correlative relationship with the MBE efficiency levels.

## Chapter 6. INTERVIEW

A total of three interviews were performed as a follow-up to the survey. The basic information of the interviewees are as follows:

- Interviewee A currently works as an estimator for a North America's general contractor that serves both building and heavy civil. Interviewee A has one-year experience as an estimator and four-year experience as an BIM/VDC coordinator.
- Interviewee B currently works as an estimator for a leading privately-held national construction company and has three-year experience in that company as an estimator.
- Interviewee C currently works as a preconstruction engineer for one of the largest construction and development companies in the US and has two-year experience in that company as a preconstruction engineer. The responsibility of Interviewee C is similar to that of an estimator. In addition, Interviewee C is also in charge of training other employees of MBE tools and software.

### 6.1 MBE IMPLEMENTATION STATUS

The three interviewees provided very different answers to the question of how MBE is implemented in their projects. Since MBE is still being developed, each company is exploring the use of MBE in their projects, and, as a result, each company has developed a unique workflow to implement MBE that best suits their needs.

Interviewee A said they would first review the design model thoroughly, and extract as much information as possible from the model. They generally make the decision about which information is reliable, based on their experience. Afterwards, they would use the model as a

visualization tool while performing a 2D QTO. Interviewee B stated they would first have their BIM department work with the design team to refine the model to an acceptable quality for QTO; then they would start to extract quantities from the model automatically and verify the quantity before pricing it. Interviewee C responded that they would verify the model first, and use a color code to see if each building system is well defined and categorized. After that they would send the model back to the design team to have them verify and adjust the model according to their comments. They would then start to extract the model automatically when the model is revised to an acceptable quality.

The responses from the three interviewees indicate that the model initially given by the design team is generally not reliable. To implement the model to a higher level more efficiently, more frequently, and for more trades and elements, the personnel from the general contractor side, such as estimator or VDC engineer has to work with the design team and help them improve the quality of the model. Thus, the author believes that the more the design team and general contractor are integrated in the project, the more effective the communication will be between the estimator and the design team and the more enhancement the model could provide to the project. To confirm this, the author asked the interviewees to share their opinion on the relationship between MBE and various project integration factors. The results will be presented in the next section.

## 6.2 MBE AND PROJECT INTEGRATION

All three interviewees confirmed that the project integration could foster MBE implementation, because collaboration between the design team and the general contractor can increase the chance for them to work together toward improving the model quality and make it suitable for MBE. However, one of the interviewees also asserted that in the realm of project integration, the owner plays a key role, because the owner pays the design team. Therefore, the

design team would be more willing to make adjustments to their model, if they were asked to provide a high-quality model by the owner, instead of the general contractor.

They also mentioned that the project delivery method is also important for the following reasons:

- (1) In a project delivered in IPD or DB, there is a greater chance that the design team will be willing to share their model with the general contractor, which creates a good starting point for the general contractor. If the model is not provided, the general contractor would build their own model, yet there will be a discrepancy between the general contractor's model and the design team's model. The general contractor would not fully trust the model until the design team approves the model, which may lead to low MBE efficiency.
- (2) In IPD or DB, subcontractors would be required to provide a model in the very early design phase, and it can increase the percentage of the total costs being calculated with MBE.

Although the interviewees confirmed that project integration and project delivery methods should have an influence on MBE, the survey results in Chapter 5 did not show any correlation between project integration/project delivery methods and MBE implementation. To determine the reason behind this, the author attempted to ascertain the factors preventing the industry from implementing MBE to a higher level, so as to offer a viable solution to improve MBE implementation.

### 6.3 CHALLENGES FACED BY MBE AND SOLUTION

The challenges faced by general contractors, as mentioned by the interviewees, that stop them from implementing MBE to a higher level are summarized as follows:

- (1) The model produced by the design team is not adequately structured to make MBE feasible and is usually not trustworthy. At times, the model even exhibits critical errors. In fact, the design team would sign an agreement with the general contractor before even sharing the model to ensure they would not be held legally liable, should the model not provide accurate information. Most design teams that the interviewees worked with can only produce a model that is very rough and far from being accurate. Even if the general contractor provides feedback and requires them to make adjustments accordingly, they would usually not alter anything for the general contractor.
- (2) Not everyone is interested in MBE. A substantial number of individuals prefer the traditional 2D estimation method. In addition, MBE takes a long time to learn and normally does not display its effectiveness in a short time period like other information sharing tools such as Procore and Primavera 6. It appears that industry practitioners display reluctance toward MBE in the current industry.

One of the interviewees offered a constructive advice to overcome these limitations. The interviewee asserted that it is the responsibility of the general contractor to lead the evolvement of utilizing more MBE in the industry, because the general contractor can attain the most benefits from implementing MBE. In the current industry, the function of the design team supporting MBE in the design phase is either for marketing purposes or because they are required by the owner. In other words, they do not have a proper motivation to make the necessary improvements. Therefore, the general contractor should lead the involvement by convincing the owner that value can be added to the project if MBE is implemented at a high level. The commitment of the owner will make it much easier for the general contractor to help improve the model quality of the design model and make it more feasible to implement MBE.

Although MBE is facing substantial and numerous challenges, the interviewees stated that MBE certainly represent the future method of estimating. To understand the challenges faced by MBE, the author asked the interviewees to evaluate MBE's influence on a project to check if any negative outcomes were observed by the interviewees, since these negative MBE outcomes could provide reasons to stop the industry from implementing MBE to a higher level. The results are summarized in the following section.

#### 6.4 MBE INFLUENCE

All three interviewees relayed that MBE can bring benefits, rather than cause issues. The following benefits can be achieved by implementing MBE:

- (1) MBE saves the general contractor a large amount of time, especially during the early design process.
- (2) A model provides more information than traditional 2D plans, and is a very helpful tool for the estimator to use to develop a more comprehensive understanding of the project, especially in the early design phase.
- (3) The owner can profit from MBE implementation, since it would facilitate and offer a clearer visualization of what is included in the budget.
- (4) MBE is good for marketing.

The only disadvantages the interviewees mentioned were that they need to pay more attention on training their employees in improving their MBE skills, and they will have to hire additional experts to operate MBE, which is an additional cost to them. Thus, this could possibly be a reason why most general contractors have currently not been able to implement MBE to a higher level.

The interview indeed offered the author a deeper insight into this topic. All three interviewees shared cogent points regarding the MBE implementation status in the current industry and detailed information was garnered that contribute to understanding the survey results. In the next chapter, the author will summarize and combine the results of the survey and interview to provide an in-depth discussion regarding the relationship between project integration and MBE.

## Chapter 7. CONCLUSION AND FUTURE RESEARCH

### 7.1 CONCLUSION

#### 7.1.1 *MBE Efficiency*

The survey results illustrated that information is negatively related to the MBE efficiency. According to one of the interviewees, there are certain situations where time is limited for the general contractor. For example, the owner is in urgent need of the total budget amount in the early design phase to make an appropriate decision. In that case, the general contractor would sometimes automatically extract quantities from the model provided by the design team and price them for the owner. Once it is determined that the calculated budget is inaccurate, the general contractor will use the model's low quality as an excuse, when telling the owner that the budget is not accurate, because the design was not completed as yet and that the model provided by the design team is not accurate during this period. In this scenario, although MBE is implemented on a very high efficiency level, the general contractor and the design team tend to blame and conflict with each other in this situation, rather than entering into a productive collaboration to resolve the problem. This can be an explanation for the negative correlation that was found between project integration and MBE efficiency. To discover a possible solution to this, the author delved deeper into the issue. The essential reason for the conflict is that, the general contractor and the design team are signing separate contracts with the owner. Thus, the author believes that in DB and IPD projects, this situation could be avoided since the general contractor and the design team sign an integrated contract with the owner. Inspired by this, the author conducted another ANOVA analysis between projects where separate contracts are signed and projects with an integrated contract. The results are depicted in Table 7.19., and it can be

seen that the p-value is 0.033 and the average MBE efficiency of projects with an integrated contract is higher than projects with separate contracts ( $4 > 3.625$ ).

Table 7.19. ANOVA Analysis between Projects with Separate Contracts and Projects with an Integrated Contract

		N	Mean	Std. Deviation	Std. Error	F	Sig.
Efficiency	CM at risk and DBB	16	3.625	1.360	0.340	4.101	0.033
	Design Build and IPD	4	4.000	1.155	0.577		
	Other	2	1.000	0.000	0.000		
	Total	22	3.455	1.471	0.314		

The two challenges faced by MBE implementation were explained in Section 6.3, namely, the low quality of the design model and the general contractor’s MBE skill. It can be concluded that the level of MBE efficiency is decided by two factors: the design model’s quality and the general contractor’s skill, experience, and trust in MBE. Figure 7.1 illustrates the matrix indicating how the factors influence the MBE efficiency level.

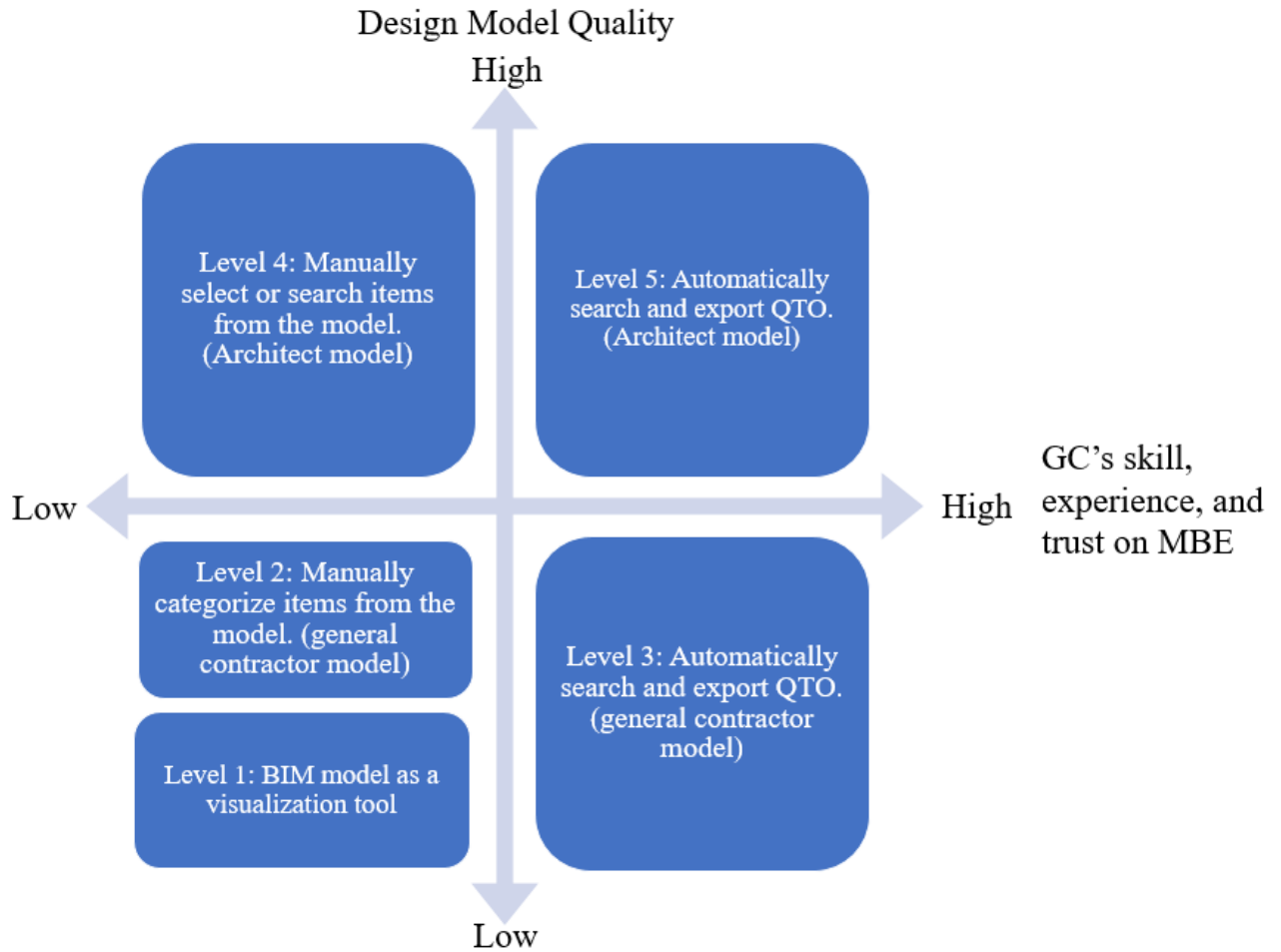


Figure 7.1. MBE Efficiency Level Matrix.

As was confirmed by the interviewees, positive collaboration between the design team and the general contractor can assist in improving the design model's quality. However, the owner has a more influence on the design team in improving the design model's quality. Moreover, the project integration factors developed from the literature review do not offer sufficient weight to the role of the owner, which provides an explanation for the uncorrelated statistical results. On the other hand, the general contractor can only develop trust in MBE after the employees exhibit proficient skills in MBE and the general contractor has gained experience in a project that has been estimated by MBE. Naturally, this situation cannot be changed in the short term by merely putting effort into improving project integration.

### 7.1.2 *MBE Frequency*

According to one of the interviewees, an effort toward increasing MBE frequency depends on whether it is worth doing so, and whether MBE could prove more beneficial to the general contractor other than result in hassles.

The statistical results revealed that information sharing, data structure, aligned goals, and resources have positive correlation with MBE frequency, and those project teams who focus on improving the four factors employ MBE more frequently. Moreover, a good environment to implement MBE requires adequate and open information sharing, a well-defined data structure, aligned goals, and sufficient resources to support active team collaboration. In this case, the general contractor would be more willing to utilize MBE more frequently, because it would not result in additional difficulties or problems.

At the same time, the statistical results showed that DBB registered higher in frequency in implementing MBE than CM at risk, while DB scored even lower than CM at risk. It indicates that project integration represents only one of the factors that have an impact on MBE frequency. Other factors may also have a significant influence, such as time limitation and design completion degree.

Usually in a DBB project the time is limited for the estimation, which may make the general contractor more motivated to find a method to save time, because MBE tools can extract quantities from the model in a few minutes. In addition, the design is usually completed in DBB when the general contractor initiates the estimation. Therefore, the model that is provided is more likely to furnish sufficient information for the estimator to implement MBE, which also makes it easier to effectively implement MBE. Although according to the interview result, it is of great chance in DBB that the design model is not shared, the general contractor could build their

own model based on the finished design to implement MBE. Either way brings a good quality model derived from a high design completion degree. Furthermore, the design completion degree for DBB is higher than CM at risk, while DB's completion degree is the lowest. This can explain why DBB showed a higher level in MBE frequency than CM or DB.

The statistical results also demonstrated that the general contractor involved from CD registers higher in frequency for MBE implementation than DD, followed by a declining number for PD and SD that has the lowest number. It can, likewise, be explained by the following factors: time limitation and design completion degree. However, the general contractor that is involved from PD has a lower MBE frequency than those involved from CD, but higher than those who are involved from SD. This could be because the typical working approach of the general contractors involved from PD is different. As both Denerolle (2013) and Tiwari et al. (2009) have highlighted in their IPD reports, the estimating and designing protocols in the general contractors involved from PD (usually happens in DB and IPD projects) are two synchronized processes and are repeated in a circle until the estimated price reaches the target budget. To better clarify this process, the workflow in Figure 7.2 provides a detailed view of the circular pre-construction process in IPD.

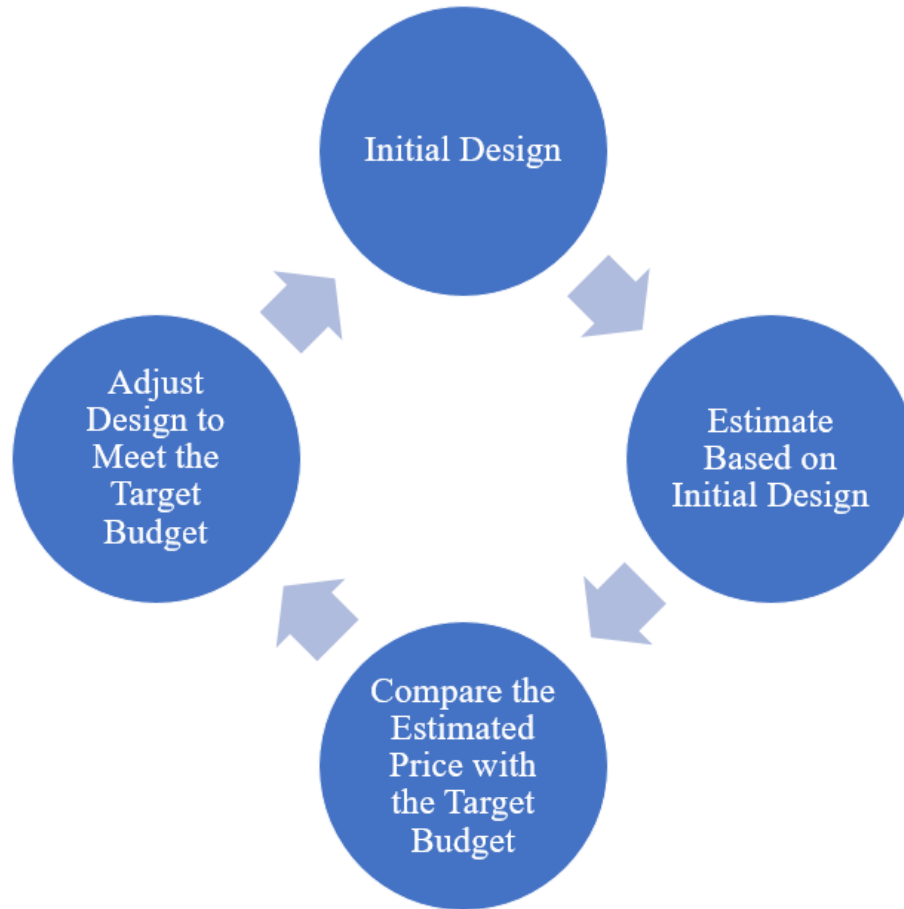


Figure 7.2. Pre-construction Estimating-designing Process in DB and IPD [adapted from Denerolle (2013) and Tiwari et al. (2009)]

In DB and IPD, the design team typically produces the initial design first, and then the estimator begins the estimation process, based on the initial design. After the estimation is completed, the project team then compares the estimated price with the total budget for the project. If the estimated price is higher than the target budget, the design team then attempts to adjust or modifies the design, so as to meet the required budget. Next, the estimator develops an adjusted estimation based on the revised design, and the process repeats itself until the estimated cost is lower than the target budget of the project. Since the estimation process is repeated several times, rapid real-time

estimation through MBE can help save time by facilitating design decision-making processes. Thus, it can be speculated that the general contractors involved from PD have a relatively high demand for MBE, which, as a result, can provide more opportunities for MBE to be used more frequently in those selected projects.

### 7.1.3 *MBE Percentage*

The statistical results showed that the MBE percentage is not correlated to the project integration factors. According to Denerolle (2013) and Tiwari et al. (2009), this can be due to several reasons as follows

- (1) Some of the estimation items are calculated by the time required for the work project, such as the general conditions.
- (2) Some of the estimation items are usually not shown in the model, such as the shoring structures.
- (3) Each subcontractor utilizes different modeling tools that best suit their needs. However, MBE cannot be implemented or encounters conversion or implementation issues in models produced by some certain software, such as AutoSprink.

The results also depicted that DBB has the highest MBE percentage. This can be explained by the completed degree of design in DBB. Because the design process in DBB is finished when the estimation starts, the estimator in this case could be able to implement MBE for more trades than that in other delivery methods. Hence, DB has a higher MBE percentage than that of CM at risk. Possible explanations for this finding are listed below:

- (1) The general contractor's typical work approach is different in DB and CM at risk. For example, the general contractor would repeat the estimation process several times to provide reference to the design team, which is the same as that in IPD. These repeating

processes of estimation in DB could encourage the general contractor to implement MBE for more trades.

- (2) According to one of the interviewees, subcontractors are more likely to provide a model in DB. The model provided by the subcontractors could be more reliable and closer to what is going to be constructed in the project. Thus, by using their model in MBE, it could bring more accurate results. Hence, the general contractor in DB is more likely to implement for trades than CM at risk.

By summarizing the research results, possible solutions can be devised to encourage MBE implementation. The lessons learned and results of this process will be listed in the following section.

## 7.2 LESSONS LEARNED

- (1) An integrated contract can help avoid adversarial relationships between the design team and the general contractor. As a result, MBE efficiency can be significantly improved, which helps the team to spend less time on the estimation and improve the accuracy of the estimation.
- (2) The owner plays a key role in requiring the design team to produce a model with better quality. If the general contractor needs the design team to improve the quality of the model, the owner should be convinced that MBE implementation can generate substantial benefit for the project, so that the owner could be more involved in enhancing MBE implementation.
- (3) MBE has a long learning curve. Although MBE acceptance and development are challenging in the industry, it could produce substantial benefits in the long run,

especially for the general contractor. MBE is regarded as the future of estimating, thus the general contractor needs to pay more attention on training their employees on MBE, so as to improve their skill and understanding of MBE.

- (4) The following factors provide a good environment for MBE implementation: adequate and open information sharing, well-defined data structure, aligned goals, and enough resources to support team collaboration. If the project team intends to promote MBE implementation to a higher level, these aspects represent the most effective factors for MBE implementation.
- (5) Usually in a project, each subcontractor would use the BIM software that best suits their needs. If the general contractor intends to use MBE in more trades, it could present a positive direction to communicate with each trade to ensure the model provided is developed in the desired software.
- (6) The delivery method used and involvement period of the general contractor also have an impact on MBE implementation. In IPD and DB, the general contractors are usually on board from the early design phase, thus the design team and the subcontractor are more likely to share the model, so that the general contractor can implement MBE more effectively. Additionally, in these two delivery methods, the general contractor has more control of the entire process of the project, therefore it is more likely for the general contractor to lead the whole project team to utilize MBE implementation.

### 7.3 LIMITATIONS OF THE STUDY

The goal of the study was to ascertain the relationship between MBE implementation and project integration, as well as the relationship between MBE implementation and basic project information: project types, project budget levels, owner types and project delivery method.

However, the statistical results did not produce the expected result. In this section, the author will list the limitations of the study for the sake of future research:

- (1) 31 responses were received in this survey, yet nine were eliminated because BIM was not used in their projects. This limited number of samples appeared to be insufficient to show correlations between MBE and project integration, as well as other factors.
- (2) The project integration factors that were developed from the literature review did not place enough weight on the owner's role in the project. The survey should have included more factors related to the owner's role, since the owner plays a bigger key role in improving MBE implementation than the collaboration between the general contractor and the design team during project integration.
- (3) IPD is not very widely utilized in the current industry compared to other delivery methods, and as a result, there was no IPD project in the survey responses received. IPD is believed to have the highest project integration. Without an IPD input, the study was not able to depict a full picture of the industry and was not able to determine how MBE is implemented in an IPD environment other than what is described in the existing literature (e.g., Denerolle, 2013).
- (4) MBE technology is still emerging and evolving, hence the learning curve of MBE is known to be long. Furthermore, not all the relative parties are interested in implementing MBE, and not everyone trusts this technology. This results in a negative attitude toward MBE, which makes it difficult to invite individuals who have MBE experience to respond to the survey.
- (5) Every organization has different practices and opinions of MBE. Each interviewee demonstrated a unique way to implement MBE. According to one of the interviewees,

some companies would even contract with a third-party modeling company to build the model for them based on 2D drawings. Thus, it sometimes creates a situation where it is difficult to decide which way is better, since professionals in the current industry are still exploring and attempting to determine the best method and workflow to implement MBE.

- (6) Lastly, it will take time for the entire industry to embrace MBE. At present, it appears that this methodology needs to be better defined and introduced in such a way that contactors will be inspired to implement MBE and train their staff accordingly.

#### 7.4 FUTURE RESEARCH

In response to the limitations of this study, the following opportunities for future research are identified:

- (1) Additional survey can be distributed to a broader audience. With an increasing number of individuals being exposed to MBE, it is necessary to broaden target survey participants. It is suggested to get responses from other positions including project engineers, superintendents, and project managers. Inviting participations from international companies can also be considered.
- (2) Another future study is suggested to add factors to represent the role of owners. According to the interview result, an owner can play a role that is more critical than a general contractor in improving the MBE implementation level. Therefore, additional project integration factors related to owners' role can be further investigated.

## BIBLIOGRAPHY

- AIA (2007a). Integrated project delivery: A guide. *American Institute of Architects (AIA), California.*
- AIA (2007b). Integrated project delivery-a working definition. *American Institute of Architects (AIA), California.*
- AIA (2011). Integrated project delivery: case studies. *American Institute of Architects (AIA), California.*
- Aram, S., Eastman, C., & Sacks, R. (2014). A knowledge-based framework for quantity takeoff and cost estimation in the AEC industry using BIM. *Proceedings of the International Symposium on Automation and Robotics in Construction.*
- Autodesk Education. (2013). Creating a Detailed Quantity Takeoff in Navisworks. Retrieved April 11, 2017, from <https://www.youtube.com/watch?v=Ck1k8n3iUzQ>.
- Autodesk Revit Tutorial. (2015). Autodesk Quantity Takeoff Tutorial. Retrieved April 11, 2017, from <https://www.youtube.com/watch?v=TS64fV2qiBU>.
- Azhar, N., Kang, Y., & Ahmad, I. (2014). Critical look into the relationship between information and communication technology and integrated project delivery in public sector construction. *Journal of Management in Engineering*, 31(5), 04014091.
- Burge, A. (2013). BIM Estimating w/ Innovaya. Retrieved April 11, 2017, from <https://www.youtube.com/watch?v=irYd9trdGAo>.
- Chitkara, K. K. (1998). *Construction project management*. Tata McGraw-Hill Education.

- Choi, J., Kim, H., & Kim, I. (2015). Open BIM-based quantity take-off system for schematic estimation of building frame in early design stage. *Journal of Computational Design and Engineering*, 2(1), 16-25.
- Denerolle, S. (2013). *The application of Target Value Design to the design phase of 3 hospital projects*. Berkeley, CA: Project Production Systems Laboratory, University of California, Berkeley.
- Eik-Andresen, P., Landmark, A. D., Hajikazemi, S., Johansen, A., & Andersen, B. (2016). Remedies for Managing Bottlenecks and Time Thieves in Norwegian Construction Projects—Public vs Private Sector. *Procedia-Social and Behavioral Sciences*, 226, 343-350.
- Garcia, A. J., Manata, B., Mollaoglu, S., & Miller, V. Key Information Sharing Behaviors for Improved Performance in IPD Project Teams. In *Construction Research Congress 2016*(pp. 1907-1916).
- Halpin, D. W. (2010). *Construction management*. John Wiley & Sons.
- Harper, C. M., Molenaar, K. R., & Cannon, J. P. (2016). Measuring Constructs of Relational Contracting in Construction Projects: The Owner's Perspective. *Journal of Construction Engineering and Management*, 142(10), 04016053.
- Ibrahim, C. K. I. C., Costello, S. B., & Wilkinson, S. (2014). Establishment of quantitative measures for team integration assessment in alliance projects. *Journal of Management in Engineering*, 31(5), 04014075.
- Kenig, M. E. (2011). *Project delivery systems for construction*. Associated General Contractors of America.

- Lee, H. W., Anderson, S. M., Kim, Y. W., & Ballard, G. (2013). Advancing impact of education, training, and professional experience on integrated project delivery. *Practice Periodical on Structural Design and Construction*, 19(1), 8-14.
- Lee, S. K., Kim, K. R., & Yu, J. H. (2014). BIM and ontology-based approach for building cost estimation. *Automation in Construction*, 41, 96-105.
- Luth, G. P., Schorer, A., & Turkan, Y. (2013). Lessons from using BIM to increase design-construction integration. *Practice periodical on structural design and construction*, 19(1), 103-110.
- Ma, Z., & Liu, Z. (2014). BIM-based intelligent acquisition of construction information for cost estimation of building projects. *Procedia Engineering*, 85, 358-367.
- Martimo, C. (2014). Material Take-Off with Cost in Currency with Revit. Retrieved April 11, 2017, from <https://www.youtube.com/watch?v=HeeMcYt7rUg>.
- Molenaar, K., Messner, J., Leicht, R., Franz, B., & Esmaili, B. (2014). Examining the roles of integration in the success of building construction projects. Retrieved November 11, 2016, from <http://www.pankowfoundation.org/grants.cfm>
- Monteiro, A., & Martins, J. P. (2013). A survey on modeling guidelines for quantity takeoff-oriented BIM-based design. *Automation in Construction*, 35, 238-253.
- Olsen, D., & Taylor, J. M. (2017). Quantity Take-Off Using Building Information Modeling (BIM), and Its Limiting Factors. *Procedia Engineering*, 196, 1098-1105.
- Osment, M. (2016). Webinar: Estimating with Vico Office. Retrieved April 11, 2017, from <https://www.youtube.com/watch?v=-T7FLBp02vU>.

- Ospina-Alvarado, A., Castro-Lacouture, D., & Roberts, J. S. (2016). Unified Framework for Construction Project Integration. *Journal of Construction Engineering and Management*, 142(7), 04016019.
- Sabol, L. (2008). Challenges in cost estimating with Building Information Modeling. *IFMA World Workplace*.
- Safa, M., Sabet, A., MacGillivray, S., Davidson, M., Kaczmarczyk, K., Gibson, G. E., Rayside, D. & Haas, C. (2015). Classification of Construction Projects. Retrieved October 21, 2017, from <http://hdl.handle.net/10012/11560>.
- Sattineni, A., & Bradford, R. H. (2011). "Estimating with BIM: A survey of US construction companies" *Proceedings of the 28th ISARC*, Seoul, Korea, 564-569.
- Shen, Z., & Issa, R. R. (2010). Quantitative evaluation of the BIM-assisted construction detailed cost estimates. *Journal of Information Technology in Construction (ITcon)*, 15(1), 234-257.
- Thomsen, C., Darrington, J., Dunne, D., & Lichtig, W. (2009). Managing integrated project delivery. *Construction Management Association of America (CMAA)*, McLean, VA, 105.

# APPENDIX A

## Survey for Implementation of Model-based Estimation

### Introduction

This survey is to investigate correlation between:

- The level of Model-based estimation implementation in your project
- The level of integration between design and construction of your project team.

In this survey model-based estimation refers to using a BIM model to accurately generate quantity takeoffs and support the development of cost estimates. Integration means the designer and builder team up in the preconstruction phase and collaborate in developing and validating project goals for project success.

The objective is to analyze how the integration of a project can have an effect on the level of model-based estimation implementation in a project.

This **short** survey is **voluntary** and **confidential**. Your valuable participation will help improve current practices of implementing model-based estimation in the construction industry. This research is conducted by:

Wenqi Zhu, master student at University of Washington

E-mail: [zhuwenqi@uw.edu](mailto:zhuwenqi@uw.edu)

This survey includes 3 parts. Part 1 will ask about basic project information. Part 2 will ask you to identify the level of model-based estimation implementation in your project. Part 3 will ask you to score the integration level of your project.

Note: Most questions are written in the present tense. However, you can also answer questions based on your previous project experience.

## Part 1

Please share information about a project you have been involved in:

1. What type of project is it?
  - a. Commercial
  - b. Residential
  - c. Heavy Civil
  - d. Institutional
  - e. Industrial
  - f. Other \_\_\_\_\_
  
2. What is your primary role in the project?
  - a. Project manager
  - b. Project engineer
  - c. Estimator
  - d. Superintendent
  - e. Foreman
  - f. BIM/VDC coordinator
  - g. Other \_\_\_\_\_
  
3. What is the contract value? \_\_\_\_\_
4. Is it a private project or public project?
  - a. Private
  - b. Public

5. What delivery method are you using?

- a. Design-bid-build
- b. CM at risk (GCCM)
- c. Design-build
- d. IPD (integrated project delivery)
- e. Other \_\_\_\_\_

## Part 2

- 1. In that project, do you create your own BIM model for estimating? Yes/ No
- 2. Do you use BIM model to visualize the project for better understanding when you are estimating? Yes/ No
- 3. Do you use any estimating function of BIM software to produce QTO (Estimating function of BIM software refers to a function to transfer model data into actionable information to support estimating process)? Yes/ No
- 4. Do you do the automatic QTO (Automatic means BIM software automatically categorizes and takes off objects from model)? Yes/ No
- 5. How frequently in your project did you produce Model-based estimation?  
**Every \_\_ weeks**
- 6. What percentage of your estimating do you think is done by model-based estimation? \_\_\_%

## Part3

1. When did your company start getting involved in the project?
  - a. Pre-design
  - b. Schematic design
  - c. Design development
  - d. Construction document
  
2. What is the team selection criteria in this project?
  - a. Low Bid
  - b. Best value: cost
  - c. Best value: fee
  - d. Qualification based selection
  - e. Other \_\_\_\_\_

How much do you agree or disagree with following statements in your project? 5 = strongly agree, 1 = strongly disagree:

	1	2	3	4	5
Open and direct <b>communication</b> is maintained between all project team members					
All participants are <b>coordinated</b> in a way that conflicts are not presented					
<b>Information sharing</b> is on-time and adequate					
<b>Trust and respect</b> are shown in work environment					
Team members show good <b>leadership</b> skills					
<b>Planning</b> phase is intensified in the project					
<b>Team structure</b> is defined up front and responsibilities of each person is clearly stated					
Data of the project is exchanged with a disciplined and transparent <b>data structure</b>					
Project <b>goal and objectives are defined in early phase</b>					
Project goals, stakeholders' goals, and individual's <b>goals are aligned</b> in the project					
<b>Contract</b> in this project fosters collaboration of the entire team					
<b>Top management team</b> believes the collaboration can bring better project results					
<b>Resources</b> in terms of knowledge, technology and specific skills are available in supporting the collaboration of the team					

Please provide any additional comments (**Optional**):