Benefit Evaluation of Implementing BIM in Construction Projects

Hui-Yu Chou 1, Pei-Yu Chen 2

1 168, Jifeng E. Rd., Wufeng District, Taichung, 41349 Taiwan, R.O.C.
2 No.3-1, Ln. 5, Zhuhe Rd., Houli Dist., Taichung City 421, Taiwan (R.O.C.)

hychou@cyut.edu.tw

Abstract. Since 2014, public construction projects in Taiwan have progressively undertaken steps to promote the use of Building Information Modelling (BIM) technology, the use of BIM has therefore become a necessity for contractors. However, issues such as the high upfront costs relating to software and hardware setup and BIM user training, combined with the difficulties of incorporating BIM into existing workflow operations and management systems, remain a challenge to contractors. Consequently, the benefits stemming from the BIM implementation in turn will affect the activeness and enthusiasm of contractors to implement BIM. While there have been previous studies abroad where the benefits relating to BIM implementation had been calculated and quantified numerically, a benefit evaluation index would require considerations for regional industry practices and characteristics. This study established a benefit evaluation index and method for the implementation of BIM suitable for contractors in Taiwan. The three main principal indexes are: (1) RCR means the effects of reducing costs associated with rework; (2) SDR & DPR mean the effects of mitigating delays that occur due to construction interface coordination or rework, as well as the effects of reducing the penalty costs associated with overdue delivery; (3) AQE means the effects of improving the ability to estimate the amounts of building materials and resources. This study also performed a benefit evaluation calculation of a real world case study construction project using the first two established indexes. The results showed a 0.16% reduction in rework costs, a 6.49% reduction in delays that occur from construction interface coordination or rework, and a 5.0% reduction in penalty costs associated with overdue deliveries. The results demonstrated the applicability of the benefit evaluation index established in this study for real world construction projects.

1. Introduction
The procurement of public construction projects in Taiwan are generally awarded to the lowest bids. According to data [1] provided by the Public Construction Commission (PCC) of the Executive Yuan for the past 5 years (2012-2016), 77% of open bid public construction projects were awarded to lowest bids, with 84% of the bids awarded based on the value of contracts. Furthermore, since 2016, the ratio of the value of contracts when compared to the total value of project estimates for all open bid public procurement projects is 87.4%. In an environment where the lowest bid is considered as favourable to procurement, such numbers suggest that profit margins for contractors of public construction projects are typically not very high. When taken into account with the additional expenses such as the cost of risk and other penalty costs as a result of overdue deliveries, the chances of contractors taking a loss on a project can be considered quite high. As a result, the sentiment of construction contractors in Taiwan towards
the global trend of BIM implementation within the construction industry continues to be one of a juxtaposition of optimism and hesitation. Contractors are optimistic of the potential for improved efficiency through visual communication by use of BIM, while also resisting the added upfront costs associated with the required hardware upgrades and staff training necessary for BIM implementation. Such sentiments could explain why even though many authorizing entities have incorporated BIM as a requirement element of public construction projects, the questions of whether the government should provide an additional budget specifically for BIM related work, or how to properly estimate a budget for such instances, continues to remain a matter of discussion and debate among those both within the industry and academia alike.

However, the topics mentioned above are centred on the core question of, “How much benefit does BIM implementation bring to a project?”. In 2016, a survey was commissioned by the PCC and administered by National Central University, with respondents represented by 124 authorizing entities who have included BIM as required work elements in the procurement of construction projects, as well as 56 companies who rank among the top 50 construction companies in terms of the number of public construction projects undertaken in areas such as planning and design, construction, and PCM among others. The results of the survey revealed that even for public construction technical service providers or experienced construction contractors, 67% of the authorizing entities and 61% of the companies list “profit uncertainty” as an underlying hindering factor to BIM implementation [2]. Such a response can be influenced by factors such as project circumstances (scope, construction difficulty and complexity, etc.), method of BIM application, and maturity level of application conditions. This also goes to show that government-led policy guidance and incentive measures for BIM implementation should maintain the capability for allowing flexibility. However, the issue of “how benefits can be evaluated” should be an issue that needs to clearly be defined and understood in order to recognize how the construction industry can advance the progress of BIM implementation. Based on the reasons discussed above, this study aims to establish an index for benefit evaluation through first, collecting and analysing prior BIM implementation benefit evaluations and case studies from several countries abroad. Next, taking into account the feasibility of BIM implementation within the current climate of construction project delivery in Taiwan, a suitable method, process, and subsequent benefit evaluation index will be established. This study will then perform a feasibility validation of the proposed evaluation index using a public construction project as a case study, while also providing recommendations as to what countermeasures can be used by contractors during BIM implementation and benefit evaluation index application within the project management process.

2. Scope of application and usage of BIM in construction projects
The nature of modelling 3D elements in BIM is tied to the concurrent database creation associated with the said elements. Therefore, drafting in BIM instantly creates specific relevant building information for each 3D element within the model. This capability, when paired with other third party software, allows for the ability to extend into dimensions such as 4D and 5D by means of generating information for all building element data as required at each stage of a project to offer the potential for full project lifecycle management virtually. Due to this potential, along with targeted business software marketing, BIM technology has begun to attract attention within the construction industry, with many sharing the perception of BIM as having infinite possibilities. Whereas in reality, the actual practice of BIM usage may be limited by factors such as software limitations, availability of necessary project information, and availability of BIM-savvy staff members, which can all attribute to not being able to realize the full range of expected results. Therefore, contractors should instead choose the most reasonable and achievable uses of BIM respective to each project, as a goal for the early stages of a project. As to the definition of which different applications of BIM are available, this study will refer to the “BIM Project Execution Planning Guide” established by the Computer Integrated Construction Research Program (CIC) at Pennsylvania State University as a basis [3]. This guide was developed by the CIC as part of the “BIM Project Execution Planning buildingSMART alliance™ (bSa) Project” authorized by the US government as part of an effort
establish a National Building Information Modeling Standard™ (NBIMS). Through years of case studies and data collection, the CIC developed a list of 25 different BIM uses. The purposes of this study, only the BIM uses designated as construction phase uses were considered, of which the remaining uses were further filtered by whether they would be currently feasible for use in Taiwan, taking into account factors such as not yet fully mature software or system capabilities, uses that in actual practice would require BIM expertise beyond what is available within the domestic industry, and finally uses with lower feasibility levels with respect to the industry in Taiwan (such as Sustainability/LEED Evaluation, Drawing Production, Site Utilization Planning, 3D Control and Planning/ Digital Layout, Field and Management Tracking). The resulting 6 BIM uses and accompanying descriptions and purposes deemed as most feasible to the construction industry in Taiwan are shown in the Table 1.

Table 1. Feasible BIM Uses in Taiwan, [3]

| No. | BIM Uses                          | Description and Purpose                                                                                                                                                                                                 |
|-----|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | Existing Condition Modelling      | To serve as part of the construction model; aids in coordination between building and roadways on surrounding site (especially pre-existing roads).                                                                          |
| 2   | Phase Planning (4D Modelling)     | To use in conjunction with third party 4D software; aids in workflow sequencing review, and project site spatial and logistical planning.                                                                                 |
| 3   | Cost Estimation (Quantity Take-off)| Provides instantaneous generation of accurate building element quantity, materials, and cost estimation based on elements in the model; aids contractor in quantity and material estimation accuracy, as well as cost control efficiency. |
| 4   | Coordination                      | Provides trade coordination for architectural, structural, and MEP models in a project by way of clash detection; offers efficient manner of uncovering and identifying potential conflicts between trades and effective resolution through coordination. |
| 5   | Construction System Design/ Virtual Mockup | Use of 3D design software to design and create virtual mock-ups of building systems such as formwork systems, glass veneers, and anchor systems, etc. Allows for constructability verification, more accurate on-site marking and layout, and reduction or elimination of potential rework, thus increasing overall construction efficiency and quality. |
| 6   | Digital Fabrication               | Using the model (or third party software) to perform virtual fabrication of complex designs, capable of size and dimensional verification of unique and specific materials or building systems. Also aids in design feasibility studies through virtual assembly of components, decreasing chances for rework while increasing fabrication accuracy and efficiency, allowing for accelerated pre-fabrication process to replace on site fabrication |

3. BIM Use Benefit Evaluation Index and Measurement Method
The 6 BIM uses with descriptions and purpose discussed above each offer potential benefits in their own right. For this study, these 6 BIM uses and their potential benefits are further developed into 3 indexes through another level of consolidation by taking into account the feasibility of each of the BIM uses in the current (the past 5 years) construction industry in Taiwan, the procurement system, and availability of necessary information needed for benefit evaluation. The 3 indexes are: Rework Costs Reduction (RCR), Schedule Delay Reduction and Delay Penalty Reduction (SDR & DPR), and Accurate Quantity Estimation (AQE). The relationships between each of the 3 benefit indexes and the 6 BIM uses are shown Figure 1. The descriptions for each benefit index are as follows, with Table 2 showing the measurement methods and data collection sources for each index:

(1) Rework Costs Reduction, RCR: Because BIM offers convenient and efficient interface coordination, contractors using BIM to undergo construction planning and drawing/model consolidation can expect higher probabilities of identifying and correcting potential interface conflicts, improvement on the distribution of construction sequencing, and more precise layout and on-site marking through identification of irregular element dimensions,
all of which allows for lowered probability of rework, decreasing the risk of construction budget overrun.

(2) Schedule Delay Reduction and Delay Penalty Reduction, SDR & DPR: Because BIM offers convenient and efficient interface coordination virtually, contractors using BIM to undergo construction planning, interface coordination, and drawing/model review can expect to cut down on actual on-site interface coordination times, or construction schedule delays resulting from rework, as well as potential reductions in delay penalties.

(3) Accurate Quantity Estimation, AQE: Because BIM is inherently an information database, accurate element quantity information can generated with the highest confidence. Therefore, contractors are able to instantly generate precise quantity take-offs from a completed model for building materials in construction projects that tend to encounter greater deviations from quantity estimates, or building materials that can potentially have greater impacts on the budget (such as concrete, reinforcing bars, scaffolds, exterior cladding/decorative materials, etc.) This provides contractors with full control of material quantities in a project, which in turn leads to cost control.

Figure 1. Relationship between the functions of BIM Uses and Benefit Indexes
| BIM Benefit Index | Measurement | Data Collection Source |
|-------------------|-------------|------------------------|
| **Table 2. BIM Benefit Index Measurement Methods and Data Collection Sources** |

(1) **RCR**
(Rework Costs Reduction)

1. Through use of BIM, compile conflicts or errors between elements location or placement, excess or missing elements, construction model management errors, frequently encountered errors at complex construction interfaces, and dimensional difficulties at irregular building components.

2. Based on actual construction experience, compile construction issues that are likely to occur if BIM was not being used \{\text{Fm}\}.

3. After estimating the rework cost \(\text{RC}_{\text{Fm}}\) likely to be caused if each issue \(\text{Fm}\) were to occur, add the total sum \(\sum \text{RC}_{\text{Fm}}\) then calculate the RCR as a ratio amount of the total construction contract price \(\text{TB}\), by using \(\text{RCR}(\%) = \frac{\sum \text{RC}_{\text{Fm}}}{\text{TB}}\).

- Interface coordination meeting minutes (using BIM as a communication tool)
- Request for Information (RFI)
- Interview with project site director

(2) **SDR & DPR**
(Schedule Delay Reduction and Delay Penalty Reduction)

1. Through use of BIM, compile conflicts or errors between elements location or placement, excess or missing elements, construction model management errors, frequently encountered errors at complex construction interfaces, and dimensional difficulties at irregular building components.

2. Based on actual construction experience, compile interface coordination issues or rework that are likely to cause delays to the schedule if BIM was not being used \{\text{Fm}\}.

3. Referring to the project schedule (critical path), estimate the amount of delays to the overall project duration \(\text{DD}_{\text{Fm}}\) if each issue \(\text{Fm}\) were to occur, to calculate the number of days, add up the sum \(\sum \text{DD}_{\text{Fm}}\), then calculate the SDR ratio amount of the designated contract performance period \(\text{TD}\), by using \(\text{SDR}(\%) = \frac{\sum \text{DD}_{\text{Fm}}}{\text{TD}}\); Delay penalty \(\text{DP}_{\text{Fm}}\) is the total number of delayed days \(\text{DD}_{\text{Fm}}\)× delay penalty ratio \(\text{DPR}\)× construction contract price \(\text{TB}\), then add the total sum \(\sum \text{DP}_{\text{Fm}}\), to calculate the DPR ratio amount of total construction contract value by using \(\text{DPR}(\%) = \frac{\sum \text{DP}_{\text{Fm}}}{\text{TB}}\).

- Interface coordination meeting minutes (using BIM as a communication tool)
- Request for Information (RFI)
- Interview with project site director

(3) **AQE**
(Accurate Quantity Estimation)

1. Identify elements in the project that requires accurate quantity estimates that can be fully modelled \{\text{Ep}\}.

2. Determine the actual quantity required \(\{\text{AQ}_{\text{Ep}}\}\), BIM model quantity \(\{\text{MQ}_{\text{ep}}\}\), and contract required quantity \(\{\text{BQ}_{\text{Ep}}\}\) (to serve as original estimated quantity) for the element \(\{\text{Ep}\}\) in the project.

3. Calculate the percentage difference from the contract required quantity \(V(\text{BQ}_{\text{Ep}})\times100\%\), and BIM model quantity \(V(\text{MQ}_{\text{ep}})\times100\%\) for the element \(\{\text{Ep}\}\), then calculate the AQE percentage difference between the two by using \(D\text{V(Q}_{\text{Ep}})(\%) = V(\text{BQ}_{\text{Ep}}) - V(\text{MQ}_{\text{ep}})\).
4. Case Study Validation of Benefit Index Feasibility

To perform a case study validation of the benefit indexes established in this study, a Design-Build public construction project was selected, where the scope of the case study is limited to the BIM uses by the construction contractor. The construction budget for this case study was NT$ 600 million, with a total building floor area of 15,700 m² and a scheduled construction duration of 770 days. The three main BIM uses in this case study were Coordination, Virtual Mockup, and Digital Fabrication. The decision for when and which BIM uses would be applied to the project was made by the site director, based on previous experience to identify areas of a project that tend to be more complex, have a higher chance of resulting in rework, or cause delays in the schedule. Through in-depth interviews with the site director for this project, and thorough compilation and analysis of collected data, 4 instances were determined to have benefited from the use of BIM in the project. The instances include: identification of areas in the design where building element locations (including structural elevations) were erroneous or had conflicting placement with other elements; identification of inconsistencies in the design drawings; beneficial for review of dimensional confirmation and layout and placement of irregular building components; beneficial for complex interface review and accurate layout and placement. Table 3 shows a description for each of the 4 instances, with the respective identified issues and resolution methods.

Table 3. Description and examples of beneficial BIM use in the case study

| BIM Uses          | Effectiveness of BIM Uses                                                                 | Examples                                                                 |
|-------------------|------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Coordination      | Identification of areas in the design where building element locations (including structural elevations) were erroneous or had conflicting placement with other elements | F1: Drawing coordinates (X5,Y2) shows conflict between ceiling and structural beams
|                   | Identification of inconsistencies in the design drawings                                   | F2: B1F drawing coordinates (X2-X3, Y5-Y7) show inconsistent location of management office door placement due to discrepancies between CAD drawings and detailed design paper drawings. |
|                   |                                                                                         | Upon confirmation with designers, door placement shall comply with location as shown in CAD drawings, while updating the detailed design paper drawings to reflect the latest changes. |
Digital Fabrication
Beneficial for review of dimensional confirmation and layout and placement of irregular building components

F3: Drawing coordinates (X1-X5, Y2) show glass veneer with slope shaped glass, totalling 9 types with 11 sizes, where the angled-cut glass must be within 5 degrees to ensure proper installation.

Use BIM to undergo precise sloped glass angle calculation to enhance the precision of prefabricated materials.

Virtual Mockup
Beneficial for complex interface review and accurate layout and placement

F4: Foundation anchors for the 6 V-shaped columns at entry plaza requires very high degree of accuracy to ensure bolts can be bolted in place.

Use Tekla and Revit to create detailed structural mockup of the V-shaped column anchor areas to ensure proper bolt placement in order to avoid interference with other reinforcing bars, while concurrently performing interface coordination between anchor system and finished flooring at entry plaza.

Table 4. Results of case study validation of BIM use benefit calculation

| BIM Benefit Indexes | Calculation                                                                 |
|---------------------|-----------------------------------------------------------------------------|
| **RCR** (Rework Costs Reduction) | The sum of rework costs $\sum \{RC_{\text{fin}}\}$ + Construction contract price $TB$ = RCR(%) |
| NT$971,243          | NT$603,000,000                 | 0.16%                          |
| **SDR & DPR** (Schedule Delay Reduction and Delay Penalty Reduction) | The sum of schedule delay $\sum \{DD_{\text{fin}}\}$ + Designated contract performance period $TD$ = SDR(%) |
| 50 days             | 770 days                      | 6.49%                          |
| The sum of delay penalty $\sum \{DP_{\text{fin}}\}$ + Construction contract price $TB$ = DPR(%) |
| NT$30,150,000       | NT$603,000,000                 | 5.00%                          |
5. Conclusions and Recommendations

For the current practice of the construction industry in Taiwan, by taking advantage of the 3D visualization and collision detection capabilities that BIM can offer, construction contractors can efficiently perform drawing/model coordination, construction planning, and complex interface coordination and integration. By tailoring to the conditions and circumstances specific to each project and identifying the most suitable BIM uses, subsequent benefits can likely be expected. This study suggested 6 BIM uses that can prove effective, based on the feasibility with respect to the current capabilities of the construction industry in Taiwan, and further classified the potential benefits offered by each into the 4 benefit indexes of RCR, SDR & DPR, and AQE, which are then grouped into 3 distinct categories. While each of the indexes are applicable across all construction industry project types, the contractor should confirm internally that the proper management system and process is in place to ensure that the necessary benefit evaluation information can be attained, as well as to maintain the completeness and accuracy of the information. For these purposes, this study proposes the following recommendations:

(1) Project staff and managing directors should be knowledgeable on the capabilities of BIM, where the directors should be able to guide a team by focusing on scopes such as drawing coordination through modeling, integration of work sequences and construction interfaces, and improving construction and layout accuracy.

(2) Project progress plans and schedule critical paths should be constantly monitored and updated in order to contend with any issues that may arise, and be able to fully control potential effects on the project duration or other actual impacts.

(3) Construction project sites should factually and accurately record any conditions or situations discovered or identified as a result from the use of BIM, while also reviewing if and how such issues can be identified beforehand in the future using BIM.

(4) Every project should designate a specific budget for modelling at the start of the modelling process, and should be considered as part of modelling staffing and schedule planning.

(5) Construction companies may consider forming BIM benefit evaluation task forces internally, serving to gradually improve the process of BIM benefit evaluation, assess the BIM implementation plan for early, middle, and later phases of projects, provide technical guidance, development, and supervision for BIM users situated on the project job site, and comprehensive analysis and knowledge management of benefit evaluation results.

References

[1] Public Construction Commission, Executive Yuan (2017), 2016 Statistics on Public Procurement, Website of Public Construction Commission, Executive Yuan https://www.pcc.gov.tw/pccap2/BIZSfront/MenuContent.do?site=002&bid=BIZS_C10603452, Retrieved at 2017/3/30.

[2] National Central University (2017), “BIM Implementation in Public Construction” Final report of commissioned professional services, Taipei: Public Construction Commission, Executive Yuan.

[3] Computer Integrated Construction Research Program (2011). “BIM Project Execution Planning Guide – Version 2.1”, The Pennsylvania State University, University Park, PA, USA.