Automation in Construction 106 (2019) 102908

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Subjective benefit evaluation model for immature BIM-enabled stakeholders

Jyh-Bin Yang*, Hung-Yu Chou

Graduate Institute of Construction Engineering & Management, National Central University, Taiwan

ARTICLE INFO

Keywords:
BIM
Empirical study
Benefit evaluation
Immature BIM-enabled stakeholders

ABSTRACT

Building Information Modeling (BIM) implementation brings many benefits for different stakeholders, but how to evaluate the benefits is still an unsolved problem. For dealing with the problem, this study proposes an overall benefit evaluation structure for BIM implementation, and then develops a subjective benefit evaluation model for immature BIM-enabled stakeholders by evaluating project-based benefits in three evaluation stages: pre-project, in-progress and post-project evaluations. Through an empirical study of thirteen BIM implementation cases in Taiwan, this study concludes that the proposed model is appropriate to evaluate project-based benefits for a stakeholder who is not familiar with BIM implementation. The research outcomes and findings of BIM benefits evaluation can assist those in the public and private sectors who have sensed the value of BIM and want to implement BIM technology. Further research to evaluate BIM benefits in different BIM implementation levels is needed.

1. Introduction

Building Information Modeling (BIM) technology has attracted a great deal of attention in the architecture, engineering and construction (AEC) industry over the last decade. Many countries have successful BIM implementation strategies [49], and BIM research has increased exponentially between 2010 and 2015 [46]. However, there have been many quick, fantastic changes over the past few years related to the use and implementation of BIM in the AEC industry [10]. Globally, the following circumstances occur. The government proposes policies and strategies to promote BIM implementation. For example, the UK, Singapore and China are the representative countries [24,49]. The AEC industry is actively involved in diversified BIM applications to solve existing problems or to provide better project outcomes, and further generates new business models. For example, the designer and contractor for public construction projects in Taiwan commonly employ BIM as a tool to demonstrate their capabilities in completing contract work with better project performances [60]. Universities aggressively pursue education, training and research and development (R&D) activities. R&D institutions and organizations pursue more advanced BIM applications in their research. Therefore, publications related to BIM in referred journals and international conferences are increased obviously. The status of BIM adoption in North America, Europe, Oceania, and Asia is advancing rapidly toward the mature stage of BIM [25]. Most participants in the AEC industry might be immature BIM-enabled stakeholders who usually encounter the problem of how to evaluate the benefits of BIM implementation. This study defines the immature BIM-enabled stakeholders as the BIM user who does have no BIM project experience or has low BIM maturity evaluated by any BIM capability maturity model, such as the Capability Maturity Model developed by the National Institute of Building Sciences [38].

Due to the lack of first-hand data regarding the real-world effects of BIM, it is unrealistic for construction stakeholders to risk widely adopting BIM [33], even if the productivity improvements and economic benefits of BIM for the AEC industry are widely acknowledged and well understood [1]. However, those benefits are generally anticipated rather than tangible. With the rapid development of BIM in the AEC industry, the real benefits, obstacles, and problems related to practical BIM implementation generate additional discussions [36]. After excluding those stakeholders in the mature stage of BIM implementation, others pursue their own anticipated benefits, which might block the development and implementation of BIM due to potential conflicts of interest. Developing an appropriate and easy-to-use benefit evaluation model provides an essential solution for all immature BIM-enabled stakeholders.

Previously, two approaches (a five-metric approach (BIM capability, BIM maturity levels, BIM competencies, organizational scales and granularity levels) [53] and an ROI (return on investment) model-based approach [12]) have been proposed and discussed to evaluate BIM implementation benefits. It is possible to evaluate BIM implementation

* Corresponding author at: Graduate Institute of Construction Engineering & Management, National Central University, No. 300, Zhongda Rd., Zhongli District, Taoyuan City 32001, Taiwan.

E-mail address: jyhbin@ncu.edu.tw (J.-B. Yang).

https://doi.org/10.1016/j.autcon.2019.102908
Received 14 September 2017; Received in revised form 9 June 2019; Accepted 11 July 2019
Available online 15 July 2019
0926-5805/

benefits based on diversified dimensions or viewpoints. Furthermore, there are two popular BIM maturity evaluation systems, the BIM maturity levels (level 0 to level 3) [6] and the BIM maturity index levels (levels of initial/ad hoc, defined, managed, integrated and optimized) [52]. However, most organizations that are not familiar with BIM implementation or that are at the low maturity level resist adopting such comprehensive approaches to evaluating their BIM implementation benefits. It is necessary to develop appropriate approaches at different levels to evaluate BIM implementation benefits. Although the ROI is an acceptable approach to evaluate the benefits of BIM implementation, collecting the required information for ROI calculation by immature BIM-enabled stakeholders is difficult. These situations illustrate the need for an easy-but-useful benefit evaluation model for immature BIM-enabled stakeholders. The purpose of this research is to present a subjective benefit evaluation model for BIM implementation that has been evaluated using an empirical study.

All BIM benefits can be divided into monetary and non-monetary benefits. If an organization needs to evaluate monetary BIM benefits, to obtain cost data and to perform a ROI analysis would be a good approach. However, due to inaccessible or unavailable cost data, it is difficult to perform a ROI analysis for the immature BIM-enabled stakeholders. Namely, they usually do not want to adopt a time- and cost-consuming approach at the beginning of BIM implementation. Furthermore, a previous study indicated that diverse stakeholders involved will subjectively evaluate the business benefits of information systems [26]. It is possible to use subjective evaluation model to assess BIM benefits. This study proposed a subjective benefit evaluation model, in which all BIM benefits are easy to evaluate.

The methodology used in this study is summarized as follows. For developing a benefit evaluation model for BIM implementation, this study first reviewed possible evaluation approaches and selected one economic evaluation method (cost-benefit analysis method) because it uses easy-to-obtain information. Furthermore, this study discussed possible benefit evaluation levels for BIM implementation and determined one level (project-based) for further development considering that the AEC industry is a project-based execution environment. Following an input-process-output (IPO) model from the system engineering and system thinking domains, this study developed a subjective project-based benefit evaluation model based on the benefit measures collected from the literature and then used an empirical study in Taiwan to test the feasibility of the proposed model. In the empirical study, this study used a case study approach that consists of selecting cases, analyzing cases and reporting results, which are illustrated in Section 5. Finally, the proposed model is validated by several discussions based on the outcomes of the case study.

The paper is organized as follows. In the next section, this paper reviews the literature regarding the benefits evaluation for BIM implementation. In Section 3, this study proposes a benefit evaluation structure for BIM implementation and discusses all possible benefits. In Section 4, this paper illustrates a subjective benefit evaluation model that is designed for evaluating the project level benefits of BIM implementation. Section 5 presents an empirical study of the proposed model using thirteen BIM implementation cases in Taiwan. The last section draws a conclusion and provides further research suggestions.

2. Review of BIM benefit evaluation

2.1. BIM's values and benefits

Dodge Data and Analytics (formerly McGraw Hill Construction) has published a series of reports on the business values of BIM for different stakeholders in different countries and areas [5,19–24,32,61]. The reports are designed to help stakeholders in the AEC industry improve their competitive business positions by expanding their knowledge and understanding of key industry trends. The valued information in those reports includes (1) economic and regulatory dynamics of the market, (2) new product innovation and (3) industry productivity and ROI outcomes. However, those reports clearly illustrate that the ROI information in the reports is obtained from survey results that reflect respondents' perceived ROI and are not the result of a prescribed approach to calculation [61].

Positive returns on investment with BIM implementation are commonly recognized. For the time and expense put into making BIM part of their practice, project stakeholders gain a range of benefits that include improved productivity, enhanced quality, increased opportunities for new business and overall better project outcomes [61]. Based on the reports by Dodge Data and Analytics [5,19–24,32,61], the common benefits of implementing BIM include (1) improved overall project quality, (2) better cost control/predictability, (3) fast client approval cycles, (4) reduced conflicts during construction, (5) improved collective understanding of design intentions, (6) reduced changes during construction, and (7) a reduced number of RFIs (requests for information). Those benefits are the basis for developing the subjective benefit evaluation model presented in this study.

2.2. Objective and subjective evaluation

Different institutions give different definitions for BIM. This study adopts the definition from PMBOK® Construction extension by Project Management Institute: BIM is an information-based system of processes involving the generation and management of digital representations of physical and functional characteristics of construction projects creating long-term value and enhancing the possibility of innovation [43]. That is, BIM can be regarded as one kind of IT/IS. To evaluate investments related to information technology (IT) or information systems (IS), objective and subjective evaluation approaches have been discussed. Objective evaluation methods include cost benefit analysis, value analysis, multiple criteria and others. Subjective methods include user attitude surveys, user utility function assessments, Delphi evidence, and others [42]. Many evaluation approaches have been proposed. However, the rule of “if you cannot justify your evaluation target objectively, then use subjective techniques” commonly applies [42].

The features and problems of implementing BIM are similar to those of other IT/IS techniques. Therefore, the benefits evaluation of BIM implementation can adopt the approaches informed by the IT/IS domain. For addressing the problems encountered by immature stakeholders in BIM implementation, the cost-benefit analysis approach can be considered. However, this study does not select cost-benefit analysis approaches due to the lack of confidential cost data. Excluding the cost dimension, this study focuses on exploring the benefits by using one subjective technique, the user attitude survey [2].

2.3. Objective benefit evaluation in BIM implementation

How to quantify the benefits of BIM implementation is a problematic task and certainly attracts research attention. Exploring benefits through investigating real cases is a major method. For example, to explore the benefits on a cross-section of construction projects, after analyzing secondary data from 35 construction projects with BIM implementation between 2008 and 2010, a previous study concluded that major reported positive benefits include cost reductions and controls, time savings, communication improvements, coordination improvements and quality increases or controls [7]. In that study, the discussed negative benefits mainly focused on the use of BIM software. The approach used for evaluating BIM implementation benefits in the above study can be regarded as a subjective evaluation approach since the method of content analysis is used and the researchers play a key role in determining the final evaluation results.

As stakeholder involvement in BIM implementation deepens and they receive more value from the practice, the outcomes of subjective evaluation approaches cannot provide sufficient evidence to answer whether BIM implementation brings satisfactory returns. However,

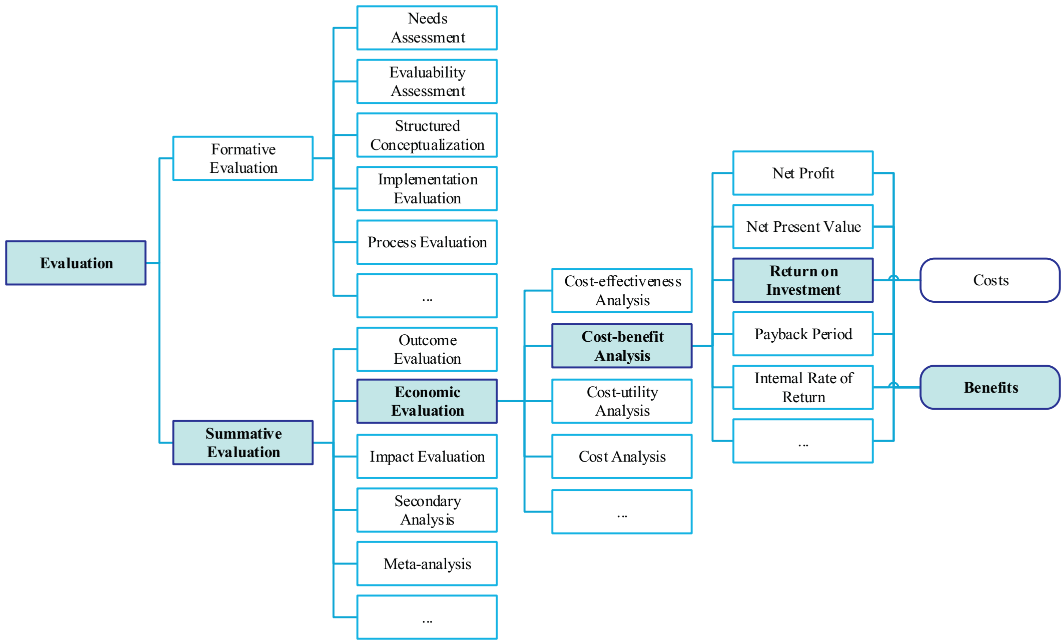

Fig. 1. Types of evaluation and its approaches.

objective evaluation approaches meet the needs. The key benefit of an objective evaluation is that the evaluation result is clear and not affected by the evaluator's views and biases.

A simple way to evaluate the benefits of BIM implementation is to compare non-BIM and BIM projects to determine if the utilization of BIM is beneficial. By considering some key features in the investment (design and construction costs) and return (RFIs, change orders and duration improvements) dimensions, three case studies that utilize an examination of non-BIM versus BIM projects have revealed some possibilities [3]. Furthermore, to encourage greater adoption of BIM technology in the AEC industry, more studies have been conducted in the past few years by using ROI to construct appropriate frameworks for quantifying monetary investments and savings [1,7,12,31]. It is clear that using ROI to evaluate BIM implementation benefits is acceptable.

After reviewing the information from ten construction projects provided by a general contractor, a previous study concluded that the average BIM's ROI for projects is 634% [1]. Notably, the project delivery method in the studied cases is the CM-at-risk method with a guaranteed maximum contract price that brings a positive incentive for contractors to save money. Furthermore, previous studies commonly use perceived ROI [4,5], even though received ROI provided more convincing evidence. For example, one previous study discussed the ROI in "design validation" based on the avoidance costs of rework due to design errors and then reported that it is possible to have an expected ROI of 624% to 699% when a month was assumed to be the delay [31].

2.4. Necessity of a subjective evaluation model

Won and Lee reviewed a lot of studies that evaluate benefits from BIM projects, and then proposed an assessment model that adopts a goal-driven approach to consider several key performance indicators (schedule, design errors, change orders, response time and ROI) rather than a pure ROI measure [59]. They identified some limitations on using ROI, including focusing on the best practice case; reporting the final ROI value based on undisclosed calculation method; requiring additional work for project engineers to collect the data required for ROI analysis; being difficult to convert the prevented errors (BIM is most beneficial in reducing errors) into a monetary value. This research clearly claimed that a pure ROI analysis is not an ideal approach of BIM benefits evaluation for immature BIM-enabled stakeholders.

A complete ROI-based benefit evaluation approach has to consider many factors when calculating ROI values [12,17]. Most organizations that do not have sufficient knowledge and experience in BIM implementation have difficulties collecting the required cost-related data, which makes it impossible to perform ROI calculations. For example, the cost-saving of reducing rework is received through conflicts detection using BIM. These potential cost-savings are received but they are difficult to measure. This makes performing a ROI analysis is time- and cost-consuming. This study attempts to provide a subjective benefit evaluation model that is an alternative approach for producing convincing BIM benefit values. Furthermore, a qualitative analysis supplements quantitative factors to develop an iterative measurement and analysis framework of existing performance to improve BIM capabilities and achieve differentiation [9]. This study proposes a subjective evaluation model that belongs to a qualitative analysis. It can provide obvious values as an alternative to a ROI analysis when it is hard to perform. For immature BIM-enabled stakeholders or beginners in BIM implementation, the proposed model will be a preliminary benefits evaluation tool when they cannot access required cost-related data for ROI-based methods.

3. Benefit evaluation structure for BIM implementation

3.1. Common benefit-related evaluation methods

Implementing BIM usually requires many resources and expenses. In today's resource-constrained environment for construction projects, an economic evaluation is necessary for any stakeholder. The evaluation or performance measurement can serve both formative and summative evaluation purposes [58]. Therefore, the methods for benefit evaluation are divided into two major types, formative evaluation and summative evaluation. Fig. 1 shows a hierarchical structure that contains many evaluation methods. This study focuses on one economic evaluation method, the cost-benefit analysis method. In cost-benefit analysis, the total costs (quantifiable and non-quantifiable costs) and total benefits (quantifiable and non-quantifiable benefits) are considered, regardless of the utilized calculation approach (ROI or others). This study concentrates on the benefits perspective only.

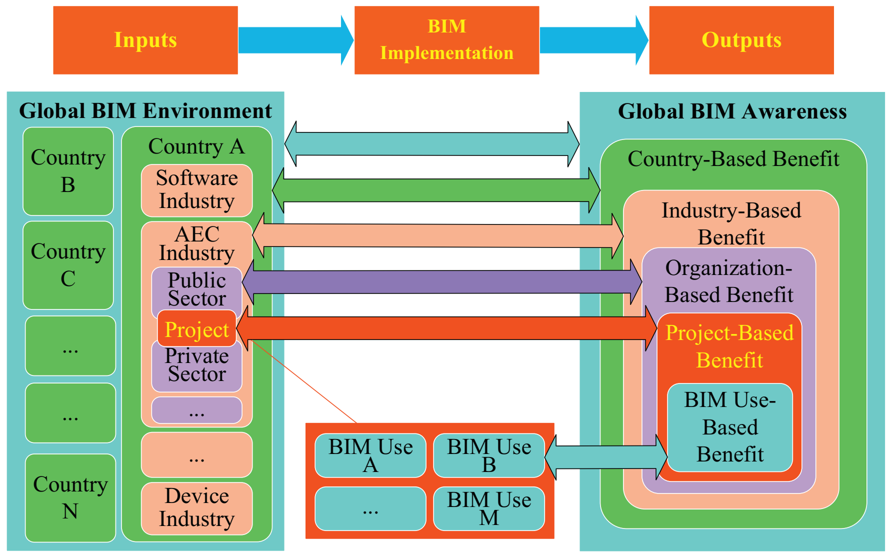

Fig. 2. Benefit evaluation structure for BIM implementation.

3.2. Benefit evaluation structure

This study discusses the benefits of BIM implementation using the input-process-output (IPO) model. The IPO model is described as putting information into the system, performing some analyses based on recorded information and then displaying its results. The model is commonly used in system engineering and system thinking domains. It is also applied to the construction domain [27].

The I/O (input/output) diagram for benefit evaluation of BIM implementation is shown in Fig. 2. For evaluating BIM implementation performance, it is necessary to consider both input and output dimensions when a different BIM use/application is implemented. In each level, the inputs vary and usually depend on the constraints of an investigation unit. For a construction project with BIM application(s), the inputs by different stakeholders are varied but the outputs are clear according to the project's viewpoint.

Regarding BIM implementation, this study classifies all benefits into six levels that consist of contextual, country-based, industry-based, organization-based, project-based and BIM use-based benefits. For each benefit, its inputs and outputs and the essential information are discussed in the following section.

3.3. Benefits in different evaluation levels

3.3.1. Contextual benefit

The contextual benefit of BIM implementation is a global BIM awareness that makes the stakeholder in the AEC industry known to move forward when the BIM era is coming. This type of benefit provides an opportunity for all stakeholders to avoid invisible losses caused by late involvement and consequently brings perceptible benefits that are later discussed as other level benefits.

A few previous studies [11,28,39] have discussed this issue. However, it is hard to measure this type of benefit. The technology acceptance model [56] could be a possible evaluation tool for measuring the contextual benefit of BIM implementation.

3.3.2. Country-based benefit

It is well recognized that the client is a major beneficiary of BIM implementation [21,35]. The government is the largest client in BIM implementation and receives a majority of the benefits from BIM implementation. Therefore, most countries are actively involved in promoting BIM adoption. A number of regions and countries are developing successful implementation strategies, including North America, the United Kingdom (UK) and the Scandinavian region [49]. Previous studies have discussed varied implementation strategies, but concentrating on country-based benefits is rare, since a country-based benefit is complicated and hard to evaluate. Providing a clear target is necessary when the government strategy has been set. For example, the UK provides an estimation of benefits in its industrial strategy related to BIM adoption. Those benefits are “a 33% reduction in the initial cost of construction and the whole-life costs for built assets,” “a 50% reduction in the overall time from inception to completion for new-build and refurbished assets,” “a 50% reduction in greenhouse gas emissions in the built environment,” and “a 50% reduction in the trade gap between total exports and total imports for construction products and materials” [16].

For any country in which the AEC industry performance differs due to government systems and industry environments, they have to consider key environmental factors when measuring and predicting BIM implementation benefits. That could be a key issue when evaluating the performance of the government's BIM strategies.

3.3.3. Industry-based benefit

BIM economic effects spread throughout both the construction industry and the whole built environment sectors, including property, construction and facilities management [47]. Discussing the values from the emergence of BIM technology can provide more evidence to induce increased investments. Although BIM offers a great potential tool to achieve the AEC industry's objectives, previous studies mainly focus on project-based benefits, such as decreasing project costs, increasing productivity and quality, and reducing project delivery time [1].

For the past few years, BIM implementations and discussions continue to increase in intensity as more organizations and national bodies recognize its value-adding potential [51]. However, BIM brings different values for different industries. Even as discipline-wide participation is discussed [14,47], the AEC industry attracts the most research attention. Furthermore, previous studies have focused on reporting potential or perceived benefits based on surveys [4,10]. It is still necessary to develop a suitable and systematic macro benefit evaluation model to evaluate industry-based benefits. That would provide increased motivation for greater involvement, which is necessary for the BIM implementation atmosphere. Recently, a study, proposing an outcome-linked benefit sharing model (OLBSM) to incentivize inter-firm cooperation in the context of BIM implementation, could help the AEC industry realize synergistic value-creation of construction projects [62].

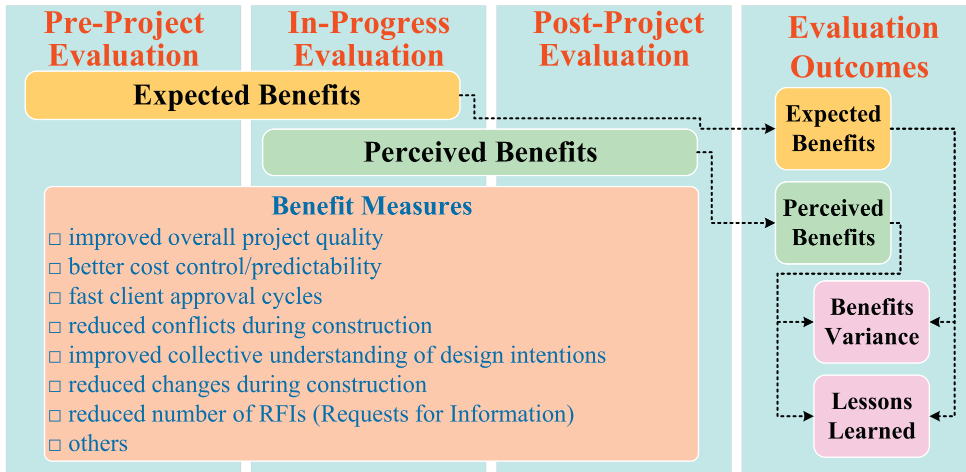

Fig. 3. Model framework of subjective project-based benefit evaluation model.

3.3.4. Organization-based benefit

Many stakeholders involved in BIM implementation receive different levels of benefits. Based on discussing the players, deliverables and interactions in BIM fields, the stakeholders are identified, and they include researchers, educational institutions and insurance companies in the policy field. There are also architects, engineers, estimators, surveyors, and developers in the process field and software, hardware, network and equipment companies in the technology field [51]. While the BIM era is coming, professional organizations or firms related to those stakeholders face different challenges and might receive varied benefits.

There is no doubt that all AEC-related organizations using BIM technology is one irresistible change in the practice. If the benefits from BIM implementation are tangible, professional organizations and firms will put more effort into pursuing more business values. However, a well-organized BIM benefit evaluation model that measures real values and is suitable for organization-based benefits is lacking. Previous research has attempted to discuss these issues and concluded that more studies on the organizational perspective of BIM are needed. In particular, more attention needs to be devoted to the organizational challenges of implementing BIM for business value [55]. In the construction industry, the evaluation methods for enterprise resource planning systems (ERP) are definitely worth noting [8,41]. Recently, a quantification model by means of system dynamics modeling to simulate the economic implications of BIM is proposed and examined by a case study [40].

3.3.5. Project-based benefit

Construction businesses are naturally project-based. Project-based benefits of BIM implementation are theoretically easy to measure. However, the cost-related burden of BIM implementation to a project is commonly hard for most organizations to accept due to BIM's perceived high initial costs. It is now necessary to develop a suitable project-based quantification approach of BIM's benefits [33,36].

Previous studies have primarily employed the case study approach to calculate project-based benefits and a project's ROI on BIM implementation [1,3,7,12,31,34,36], which were discussed earlier in this paper. However, it is notable that the range of expected and received ROI value is wide and diverse for different project stakeholders/types/stages/BIM-uses. The question “What are the reasonable benefits and ROI value for a project with BIM implementation?” would be another necessary topic to explore.

3.3.6. BIM use-based benefit

BIM use is defined as a method of applying BIM during a facility's lifecycle to achieve one or more specific objectives [29]. There are many BIM uses proposed and implemented in practice, and the scope of BIM use is still expanding [48]. Although choosing appropriate BIM uses is necessary when considering defined implementation objectives, most stakeholders might focus on basic BIM uses. For example, the National BIM Guide for Owners in the US addresses that the following essential BIM uses should be applied on all projects: existing conditions, design authoring, design review, coordination and record modeling [37].

When several BIM uses are implemented simultaneously in a project, it is difficult to distinguish the independent benefits or ROI of each BIM use. Previous studies have attempted to investigate the benefits of “design validation” based on the avoidance costs of rework due to design errors [31]. However, only limited BIM uses are investigated there. If the benefits of each BIM use can be evaluated, the results would be useful when selecting favored BIM uses. Appropriate benefit evaluation models for different BIM uses require more investigation. A goal-driven approach has been proposed to deal with the benefit evaluation in this level [59].

4. Subjective project-based benefit evaluation model

4.1. Model framework

For evaluating project-based benefits, this study proposes a subjective BIM benefit evaluation model in which the BIM implementation benefits are evaluated in the pre-project evaluation, in-progress evaluation and post-project evaluation stages. Fig. 3 shows the model's framework. With the proposed model, the stakeholders in a project that has BIM applications can evaluate expected and perceived benefits using the user attitude survey approach in the three independent stages. Based on the references in benefits evaluation [15,50,57], the expected benefits are defined as the benefits a project might have after BIM implementation and the perceived benefits are defined as the benefits a project actually have after evaluation. It is expected that expected benefits are identified in the stages of pre-project evaluation and in-progress evaluation and that perceived benefits are identified in the stages of in-progress evaluation and post-project evaluation. At the end of the evaluation, expected and perceived benefits are compared to clarify the variances and to identify the lessons learned for further BIM implementation. In sum, the benefit evaluation outcomes consist of expected benefits, perceived benefits, benefits variance between expected and perceived benefits, and lessons learned for determining BIM uses and related benefits.

For most immature BIM-enabled stakeholders, they do not have sufficient knowledge to develop suitable benefit measures for BIM implementation. This study suggests employing popular benefit measures that are proposed and used in most of the Smart Market Reports [5,19–24,32,61] by the Dodge Data and Analytics company. Those benefit measures can be benchmarked after an evaluation is completed. The benefit measures adopted in this study include (1) improved overall project quality, (2) better cost control/predictability, (3) faster client approval cycles, (4) reduced conflicts during construction, (5) an improved collective understanding of design intentions, (6) reduced changes during construction, (7) a reduced number of RFIs and (8) others that can be objectively proposed by the evaluator.

In evaluating an information system, the approaches of user involvement and user attitude are independently developed and used. User attitude refers to a psychological state reflecting the affective or evaluative feelings concerning a new system. User involvement refers to a belief where the user believes that a new system is both important and personable [2]. Considering the ease-of-use and workability of an evaluation model for immature BIM-enabled stakeholders, this study adopts a user attitude survey that can be objectively performed by the evaluator. It uses a questionnaire survey to retrieve feedback from the stakeholders to evaluate the BIM implementation benefits.

Furthermore, to confirm the structure and related items, this study has held two panel discussion meetings in which several domain experts were invited. Because the proposed structure is a part of a research project report (detailed information is illustrated in Section 5) [60], it has been reviewed twice. In the first meeting, participated reviewers include eight invited domain experts who have BIM implementation experience and seven representatives of organization/institution in AEC industry. In the second meeting, participated reviewers include three invited domain experts who are outstanding BIM professor, researcher and industry expert, and thirteen representatives of organizations/institutions in AEC industry. All comments for the research project and evaluation structure are responded and incorporated.

4.2. Key issues in evaluation

4.2.1. Pre-project evaluation

Before determining the expected benefits, it is necessary to determine the BIM implementation objectives and select suitable BIM uses. Regarding selected BIM uses, the expected benefits can be identified based on lessons learned and a panel discussion with domain experts and all stakeholders to avoid possible conflicts.

When determining the benefits, some key issues should be considered, which include the implementation stage in a project's life cycle, the resources available for the implementation work, and the BIM-related capability of the implementation team. It is suggested that one selects the benefit measure based on a discussion with domain experts and experienced project participants to select suitable measures and to avoid possible conflicts.

4.2.2. In-progress evaluation

After the project with BIM applications proceeds, regular meetings with project stakeholders are necessary. The meeting provides a channel for sharing experiences and discussing remedies for actions to improve the outcomes of expected benefits for the remainder of the project duration.

In the meeting, the purpose is to identify the perceived benefits and modify the original expected benefits if necessary. Notably, collecting required evidence for perceived benefits is necessary even if the proposed approach does not require that evidence. This evidence provides convincing information for the follower.

4.2.3. Post-project evaluation

When the project is completed, one consequently evaluates the perceived benefits. With the original anticipated expected benefits, confirmed perceived benefits and collected evidence, another meeting has to be held to identify the actual perceived benefits. The proposed approach adopts a user attitude survey to evaluate the benefits objectively. In identifying the benefits, all project participants must meet. All perceived benefits are discussed and confirmed by all participants. This arrangement can improve the quality of a subjective evaluation approach. Furthermore, domain experts who have participated in identifying expected benefits are invited to the meeting since they can provide more objective evaluations and avoid evaluation conflicts. The meeting also provides a function of ensuring the validity of evaluation results.

In this evaluation, the perceived benefits, benefits variance and lessons learned for identifying suitable BIM uses and benefit measures are discussed and confirmed. Furthermore, since the BIM development is quick, it is possible for immature BIM-enabled stakeholders to select inappropriate BIM uses and benefits in the early stage of a project. The following key issues are suggested to address when a post-project evaluation is conducted. These include (1) BIM uses with/without achieved objectives and their corresponding outcomes and reasons, (2) perceived benefits with required evidence and actual benefits not on the original list, (3) benefit variances and corresponding reasons, and (4) lessons learned in all stages of BIM benefit evaluation and suggestions for further BIM implementation.

5. An empirical study in Taiwan

5.1. Status of BIM implementation in Taiwan

Since 2011, the Architecture and Building Research Institute (ABRI) in the Ministry of the Interior has launched a series of research projects to investigate and prompt BIM applications in Taiwan's construction industry. The ABRI focuses on building-related sectors. Now, the ABRI has announced a BIM guide for Taiwan, which has been the reference for some real projects. In sum, the public and private sectors in Taiwan are actively pursuing BIM technology to cope with the challenges in the AEC industry.

The Public Construction Commission Executive Yuan (PCC) in Taiwan has established a platform for promoting BIM implementation in public construction works since May 2014 under the “case-by-case” and “step-by-step” strategies. The PCC takes the responsibility for planning, reviewing, coordinating, and supervising public construction projects as a whole in Taiwan. Therefore, it is clear that the government takes the lead in implementing BIM technology.

In 2016, the PCC conducted a research project to develop an owner's reference guide for implementing BIM in public construction works [60]. The research project has interviewed the stakeholders from fifteen BIM planning and implementation cases. The research team summarized the best practices of BIM implementation in Taiwan to draft the guide. They confirmed the final version through several evaluation meetings with domain experts. This study uses the cases from that research report to examine the feasibility of our proposed benefit evaluation model.

5.2. Study cases

5.2.1. Introduction to study cases

Originally, there were fifteen cases in the PCC's research project. This paper uses thirteen of those cases, excluding two cases without actual implementation updated to the end of 2016. Table 1 illustrates the basic information for the study cases. The project types in these study cases are diverse. Most of the cases do not belong to the type of building where many BIM applications were previously applied.

5.2.2. Scope of BIM application

This study classifies the BIM applications of the study cases into five stages according to a project's lifecycle, including planning, preliminary design, detailed design, construction, and operation/facility management. Fig. 4 shows the distribution of BIM implementation stages for the study cases.

Table 1
Basic information of cases used in this study.

ID	Project type	Purpose of BIM application
C01	Road	To adopt BIM technology into the design and construction stages to incorporate geometric information for construction layout and construction modeling.
C02	Sewage treatment Plant	To adopt BIM technology into the construction stage to improve project quality, and then to deliver an as-built BIM model that will be used in a BIM-based drawing and specifications management system.
C03	Liquefied natural gas project	To adopt BIM technology into the design stage to improve the design quality of main equipment and decrease the frequency of design changes in construction stage.
C04	Power distribution lines project	To adopt BIM technology into the design and construction stages to perform 3D coordination and assist construction management works.
C05	Bridge	To adopt BIM technology into the design and construction stages to perform conflict detections and quantity take-off and to solve the problems of engineering interfaces before construction.
C06	Road and bridge	To adopt BIM technology into the design stage to complete 3D designs and to resolve design conflicts.
C07	Air traffic control tower	To adopt BIM technology into the design, construction and operation management stages to improve the project's quality in design, construction and facility management.
C08	Power transforming station	To adopt BIM technology for facility management.
C9	Wharf engineering	To adopt BIM technology into the construction stage to build facility models that will be a part of the port GIS.
C10	Mass rapid transit	To adopt BIM technology into the construction stage to incorporate 3D digital topographic maps for construction simulation, environmental impact analysis and operational management.
C11	Fine art museum	To adopt BIM technology into the whole project life cycle to improve project quality.
C12	Hospital	To adopt BIM technology into the design and construction stages for design review and construction simulation.
C13	Sport center	To adopt BIM technology into the design and construction stages for energy simulation, construction inspection and construction conflict analysis.

In addition, this study classifies the BIM implementation purposes of study cases into the following primary purposes: design management, interface management, construction management and facility management. Fig. 5 shows the analysis results, where the secondary purposes of the study cases are also exhibited. It is clear that the scope of BIM application for the study cases is concentrated on the design and construction stages for the purposes of design, interface and construction management.

The results in Figs. 4 and 5 show the common situations in Taiwan. The scope of the study cases might be different in other countries since BIM applications are requested by the owner and not proactively proposed by the contractor. Furthermore, another key cause is that the benefits of BIM implementation are not well recognized. These characteristics must be considered in further research.

5.2.3. Survey implementation

To collect the responses from the participants in the study cases, the research team visited all thirteen projects. Before the visit, survey questionnaires were sent to the potential participants that might include representatives of the client, the consulting firm, the designer, the contractor and professional BIM service firms. During the visit to each project, at least one meeting was held to explain the survey questionnaire and to collect the responses.

For confirming the responses as being representative, this study uses a different questionnaire for the different roles of project participants. If the responses are different among participants in a project, the researcher will pose a question and confirm a final answer with a consensus among all participants. Namely, the outcomes that are consequently confirmed by all participants are persuasive. This study uses those outcomes as the inputs in examining the feasibility of the proposed benefit evaluation model.

5.3. Evaluation outcomes

Fig. 6 shows the overall evaluation results of the expected BIM benefits based on the thirteen cases, in which the "frequency" represents the amount of cases having discussed benefits and the "%" represents the percentage of ratio: cases having discussed benefits divided by the total number of study cases (thirteen cases) and then multiplying by 100. It is clear that five benefits are identified as convincingly expected based on the criterion of over 50% of cases recognizing the benefit. Those expected BIM benefits are "improved collective understanding of design intent," "reduced conflicts during construction," "improved overall project quality," "better cost control/predictability," and "reduced changes during construction."

Fig. 7 shows the overall evaluation results of the perceived BIM benefits based on the thirteen cases, in which the "frequency" and the "%" have the same meanings as those in Fig. 6. It is clear that only one

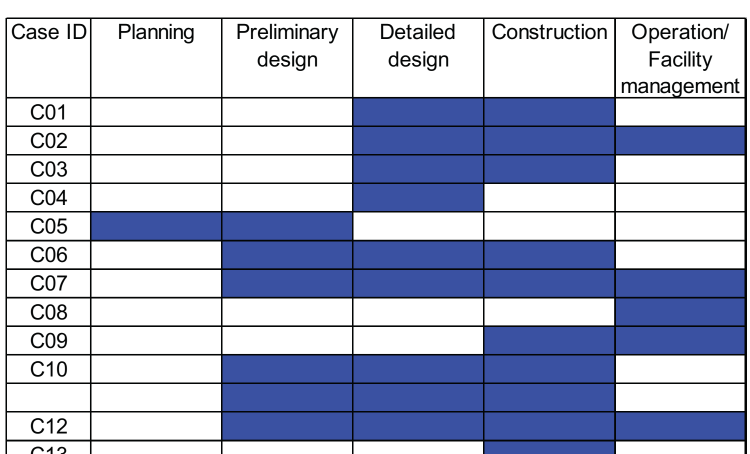

Fig. 4. Distribution of BIM implementation stages for all study cases.

Case ID	Design Management						Interface Management				Construction Management					Facility Management		
	a1	a2	a3	a4	a5	a6	b1	b2	b3	b4	c1	c2	c3	c4	c5	d1	d2	d3
C01				■										■	■			
C02			■					■	■									
C03	■	■	■	■		■	■		■		■			■				
C04	■			■			■	■	■							■		
C05	■	■	■	■											■			
C06		■		■				■				■		■				
C07			■	■					■									
C08																■	■	■
C09				■				■				■		■			■	
C10	■	■	■	■	■	■							■				■	
C11	■		■	■			■	■	■	■			■	■	■			
C12	■			■	■		■	■	■	■			■	■	■			
C13	■	■	■	■	■		■	■	■	■		■	■	■	■	■	■	■

Note: a1: Design Review; a2: Site Analysis; a3: Quantity/Cost Estimation; a4: 3D Design; a5: Sustainable Evaluation; a6: Code Validation; b1. Architecture Design; b2: Structure Design; b3: Mechanical, Electrical and Plumbing; b4. Interior Design; c1: Site Utilization Planning; c2: Construction Planning; c3: Drawing Production; c4: 3D Coordination; c5: 4D Simulation; d1: Facility Record Modeling; d2: Facility Management Planning; d3: Facility Asset Management.

Fig. 5. Distribution of BIM implementation uses for all study cases.

benefit, "improved collective understanding of design intent," is identified as a convincingly perceived BIM benefit with the criterion of over 50% of cases recognizing the benefit. Compared with the expected benefits, the perceived benefits with over 50% are fewer.

Fig. 8 shows the differences between expected benefits and perceived benefits. Clearly, the trend of recognized benefits for all items is similar and the ratio of perceived benefits over expected benefits for all benefit measures is reasonable. For all thirteen cases, only two cases completed their contract work in the investigation period. Therefore, the percentage of expected benefits being less than perceived benefits is reasonable and acceptable.

The recent report by the Dodge Data and Analytics company shows that the top three benefits of project processes and outcomes for infrastructure projects are "reduced conflicts, field coordination problems and changes during construction," "better multiparty communication and understanding from 3D visualization" and "reduced errors and omissions in construction documents" [24]. The identified expected benefits and perceived benefits in this study are similar to those above benefits. The evaluation outcomes presented above illustrate that the proposed model is workable and suitable for immature BIM-enabled stakeholders.

5.4. Discussion

5.4.1. Feasibility of proposed model in different stages

The proposed model is designed for different stages (pre-project evaluation, in-progress evaluation and post-project evaluation) of evaluating BIM implementation benefits. The cases in the empirical study cover all stages. Three cases were not started, eight cases were in-progress, and two cases were completed. The outcomes presented in the previous section show that all study cases have clear evaluation results that were accepted by the participants in those individual cases. This means that the feasibility of the proposed models has been proven.

For the immature BIM-enabled stakeholders, although the proposed model is feasible for evaluating the benefits of BIM implementation, most of them encountered a similar problem of expected benefits being different from perceived benefits because of the limited understanding of BIM implementation and its related benefits. This is a common problem for the BIM beneficiary in the early stage of BIM implementation, and a previous study considered the benefits in this stage

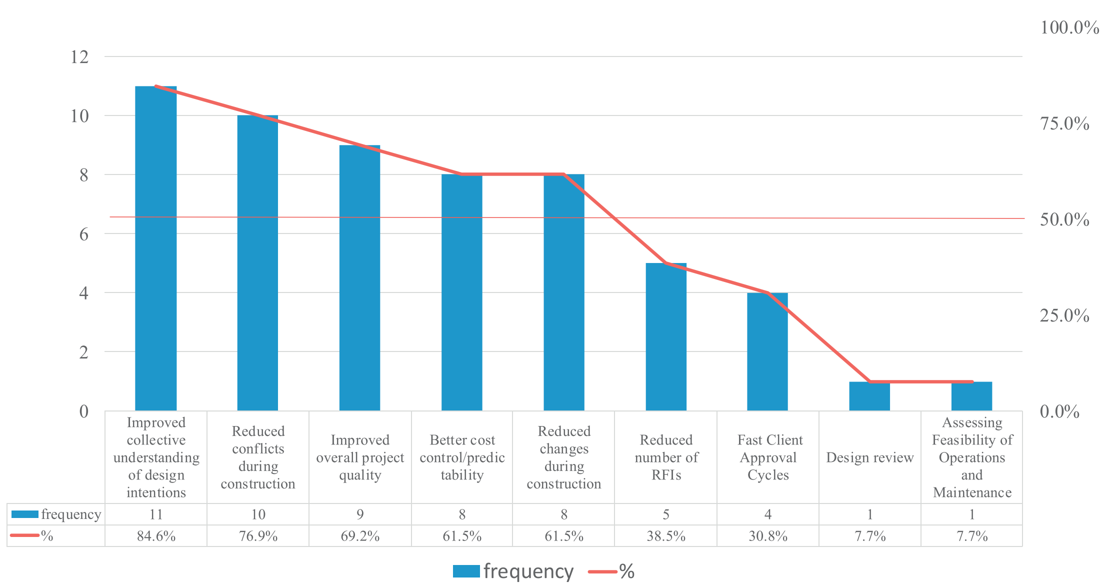

Fig. 6. Overall evaluation results on expected BIM benefits for all study cases.

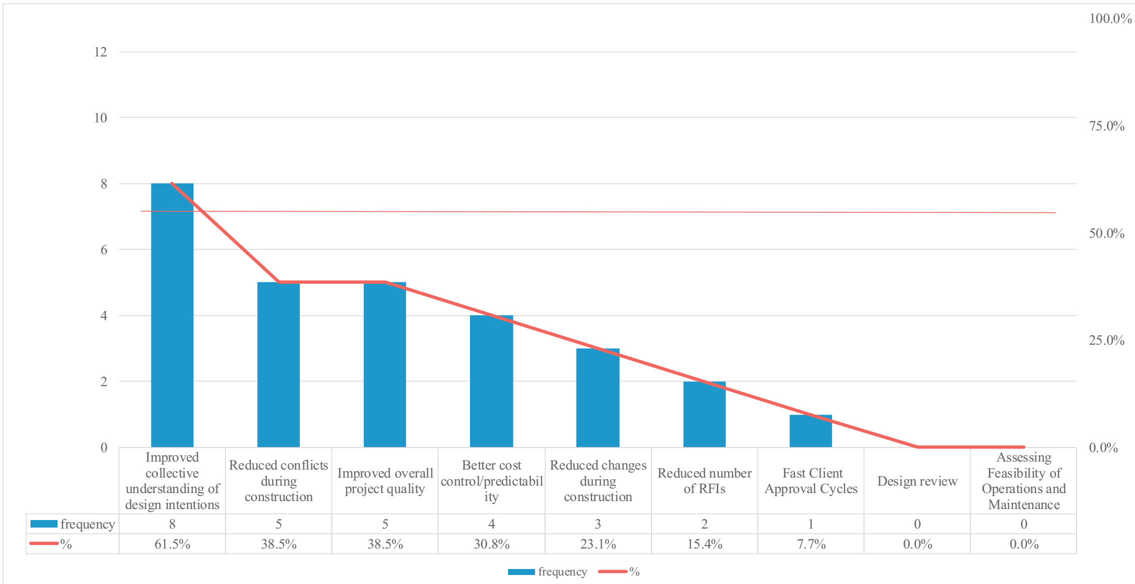

Fig. 7. Overall evaluation results on perceived BIM benefits for all study cases.

as unable to be quantified [3]. Therefore, this study has provided an alternative for resolving the benefit evaluation in the early stage of BIM implementation: a subjective benefit evaluation model.

5.4.2. Targeting suitable BIM benefits

All clients in the study cases lack experience in adopting BIM technology in their projects. This study regards all clients as being immature BIM-enabled stakeholders, although some project participants had some experience. The expected benefits were selected by the client using their understanding of BIM, BIM applications and BIM uses. Certainly, some expected benefits were unsuitably determined. This is a key feature of immature BIM-enabled stakeholders.

The proposed model considers the features of ease-of-use and workability for immature BIM-enabled stakeholders. Therefore, this study selects the benefit measures that are proposed and used in the Smart Market Reports by the Dodge Data and Analytics company. It then uses questionnaire surveys to obtain the responses related to benefit evaluation. Even with this consideration, we must consider how to target suitable BIM benefits based on the evaluator's perspective. It is suggested to refer to previous cases that are similar to the proposed

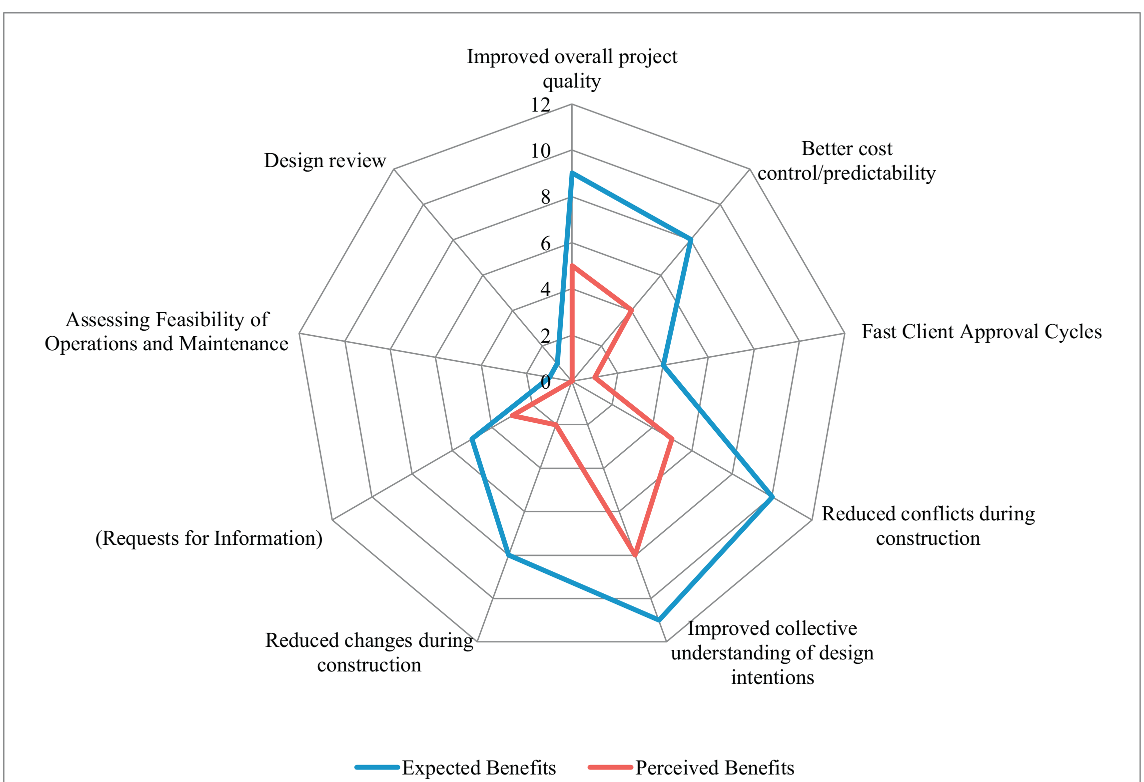

Fig. 8. Comparison of expected benefits and perceived benefits.

structure.

5.4.3. Lessons learned in study cases

In the proposed model, the lessons learned are included in the suggested evaluation outcomes. This study uses the cases from a research report. The project types of the study cases are diverse, and most do not belong to building. The difference between expected benefits and perceived benefits is appreciable. It is clear that most benefits in the infrastructure sector are similar to those in the building sector.

In the study cases, the expected benefits are determined by the client who does not possess BIM knowledge or experience. The study cases illustrate another key issue. Client BIM education and training play an essential role in successful BIM implementation with practical and achievable benefits.

5.4.4. Comparison with similar researches

This study focuses on project-based BIM benefits evaluation. Compared with similar researches, this study identifies several advantages summarized as follows.

(1) The proposed approach is a subjective evaluation model that is easy-to-use for all immature BIM-enabled stakeholders; previous researches develop a metric-based approach (BIM capability, BIM maturity levels, BIM competencies, organizational scales and granularity levels) [53] or an ROI approach [12] that is tough for immature BIM-enabled stakeholders. (2) The proposed approach is adopted in three evaluation stages (pre-project, in-progress and post-project), which is capable of recording information throughout evaluation lifecycle; others [3,7,33] focus on post evaluation after BIM implementation, which focus on final evaluation outcome [59] and are incapable of tracing complete BIM implementation lifecycle. (3) The proposed approach adopts a user attitude survey in a meeting with domain experts, which provides quality evaluation outcomes; previous subjective evaluation outcomes (such as the Smart Market Reports [5,19–24,32,61] by the Dodge Data and Analytics company) mainly depend on questionnaire survey, which provide reference evaluation outcomes with low persuasion.

5.5. Approach using proposed model

Based on the outcomes of the above discussions, this study summarizes the following steps to form a clear reference guide for using the proposed model.

(1) To select a target evaluation project that is planned to use BIM or has implemented BIM.
(2) To build an evaluation team. For the team member, BIM implementation stakeholders, domain experts and the person who has BIM implementation experience are suggested.
(3) To determine the BIM implementation objectives and select suitable BIM uses. The eighteen BIM uses in Fig. 5 analyzed in this study or the BIM uses in references [30, 37, 54] are suggested.
(4) To determine benefit measures for BIM implementation. The seven measures adopted in this study or others discussed in this article are suggested. The basic criterion to select suitable benefit measure is that measure can be objectively proposed by the evaluator.
(5) To conduct BIM benefit evaluation. The proposed model and processes including pre-project evaluation, in-progress evaluation and post-project evaluation are suggested.
(6) To report evaluation outcomes. The expected benefits, perceived benefits, benefits variance and lessons learned are suggested to collect into an evaluation report.

6. Conclusion and future works

6.1. Conclusion

Globally, BIM has been successfully implemented in the AEC industry but still faces many challenges, including benefit evaluation. This study has proposed a subjective benefit evaluation model for immature BIM-enabled stakeholders with which BIM implementation benefits can be evaluated in the pre-project, in-progress and post-project stages.

The main contributions of this article are twofold. First, this article proposed an overall benefit evaluation structure for BIM implementation and consequently reviewed the status quo of six BIM implementation levels in the proposed model. The outcomes provide a basis for further research. Second, this article proposed a subjective benefit evaluation model for immature BIM-enabled stakeholders and discussed its practicability by an empirical study. The outcomes provide a benchmark for immature BIM-enabled stakeholders who have sensed the value of BIM and want to implement BIM technology in the near future.

6.2. Future works

Evaluating or justifying investment in the IT/IS domain is problematic [42]. BIM is a new technology in the AEC industry. Stakeholders in the AEC industry face similar problems with BIM implementation. Excluding the possible research issues from discussing benefits at different evaluation levels, this paper suggests and illustrates possible research directions as follows.

6.2.1. Incorporating more precise benefit measures

This study adopts the popular benefit measures used in the serial Smart Market Reports, where only eight measures were considered. It is possible to consider and incorporate more precise benefit measures. A previous study [45] summarized thirty-one benefits (e.g., fewer errors, less reworks, lower cost). Those could be candidate benefit measures.

It is suggested that incorporating more precise benefit measures into our proposed model or developing similar models with more measures for different benefit levels provides alternative solutions for BIM benefit evaluation.

Excluding the possible values of BIM implementation for the traditional construction value chain, BIM technology brings large impacts to the AEC industry and consequently generates innovative working styles, business models and project delivery systems. To explore the value of such innovative undertakings, the potential values of interoperability in the AEC sector [13] that have been discussed elsewhere are necessary. It is possible to incorporate those innovative benefits into the model in this study in the future.

6.2.2. Developing benefits evaluation models in each level

This study has discussed that BIM implementation might bring at least six levels of benefits. For each level, its contextual information differs. Therefore, proper benefit evaluation approaches have to be developed. Previous studies merely focused on project-based benefits. More studies are required to more accurately measure benefits.

BIM implementation is regarded as a long-term investment. It is possible to incorporate more evaluation approaches shown in Fig. 1 to develop suitable benefits evaluation models for each level.

6.2.3. Developing quantitative evaluation methods for BIM-embedded projects

The feasibility of measuring the benefits of BIM with quantitative approaches has been discussed [3]. However, previous studies mainly focus on ROI approaches. Further investigation into appropriate quantitative evaluation methods for BIM implementation is necessary. Cost-related quantitative evaluation methods are more useful.

In economic evaluation methods, cost-consequences analysis, cost-minimization analysis, cost-effectiveness analysis, cost-utility analysis and cost-benefit analysis are developed [18]. In the cost-benefit analysis domain, there are many different evaluation techniques that can be categorized into five basic types: net present value methods, rate of return methods, ratio methods, payback methods and accounting methods [44]. This study suggests investigating which techniques would be more appropriate quantitative methods for measuring the cost-related benefits of BIM implementation.

Acknowledgements

The authors would like to thank the Public Construction Commission, Executive Yuan, Taiwan, for financially supporting part of this research under Contract No. 10501007.

References

[1] S. Azhar, Building information modeling (BIM): trends, benefits, risks, and challenges for the AEC industry, Leadersh. Manag. Eng. 11 (3) (2011) 241–252, https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127.
[2] H. Barki, J. Hartwick, Measuring user participation, user involvement, and user attitude, MIS Q. 18 (1) (1994) 59–82, https://doi.org/10.2307/249610.
[3] K. Barlish, K. Sullivan, How to measure the benefits of BIM — a case study approach, Autom. Constr. 24 (2012) 149–159, https://doi.org/10.1016/j.autcon.2012.02.008.
[4] B. Becerik-Gerber, S. Rice, The perceived value of building information modeling in the U.S. building industry, J. Inf. Technol. Constr. 15 (2010) 185–201 http://www.itcon.org/2010/15.
[5] H.M. Bernstein, S.A. Jones, J.E. Gudgel, The Business Value of BIM in Europe: Getting Building Information Modeling to the Bottom Line in the United Kinddom, France and Germany, McGraw Hill Construction, Bedford, MA, USA, 2010https://www.construction.com/toolkit/reports/bim-business-value-western-europe.
[6] BIS, A Report for the Government Construction Client Group, Building Information Modelling (BIM) Working Party Strategy Paper, The Department for Business, Innovation and Skills (BIS), UK, 2011http://www.bimtaskgroup.org/wp-content/uploads/2012/03/BIS-BIM-strategy-Report.pdf.
[7] D. Bryde, M. Broquetas, J.M. Volm, The project benefits of building information modelling (BIM), Int. J. Proj. Manag. 31 (7) (2013) 971–980, https://doi.org/10.1016/j.ijproman.2012.12.001.
[8] B. Chung, J.S. Mirosław, Y.H. Kwak, Developing ERP systems success model for the construction industry, J. Constr. Eng. Manag. 135 (3) (2009) 207–216, https://doi.org/10.1061/(ASCE)0733-9364(2009)135:3(207.
[9] R. Dowsett, C. Harty, Evaluating the benefits of BIM for sustainable design: a review, in: S.D. Smith, D.D. Ahiaga-Dagbui (Eds.), Proceedings of the 29th Annual ARCOM Conference, Association of Researchers in Construction Management, Reading, UK, 2013, pp. 13–23 http://www.arcom.ac.uk/-docs/proceedings/ar2013-0013-0023_Dowsett_Harty.pdf.
[10] M. Gerges, S. Austin, M. Mayouf, O. Ahiakwo, M. Jaeger, A. Saad, T.-E. Gohary, An investigation into the implementation of building information modeling in the Middle East, J. Inf. Technol. Constr. 22 (2017) 1–15 http://www.itcon.org/2017/1.
[11] A. Gerrard, J. Zuo, G. Zillante, M. Skitmore, Building Information Modelling in the Australian Architecture, Engineering and Construction Industry, IGI Global, Hershey PA, 2010, https://doi.org/10.4018/978-1-60566-928-1.ch023.
[12] B.K. Giel, R.R.A. Issa, Return on investment analysis of using building information modeling in construction, J. Comput. Civ. Eng. 27 (5) (2013) 511–521, https://doi.org/10.1061/(ASCE)CP.1943-5487.0000164.
[13] A. Grilo, R. Jardim-Goncalves, Value proposition on interoperability of BIM and collaborative working environments, Autom. Constr. 19 (5) (2010) 522–530, https://doi.org/10.1016/j.autcon.2009.11.003.
[14] N. Gu, K. London, Understanding and facilitating BIM adoption in the AEC industry, Autom. Constr. 19 (8) (2010) 988–999, https://doi.org/10.1016/j.autcon.2010.09.002.
[15] K.P. Gwinner, D.D. Gremler, M.J. Bitner, Relational benefits in services industries: the customer's perspective, J. Acad. Mark. Sci. 26 (2) (1998) 101, https://doi.org/10.1177/0092070398262002.
[16] HM Government UK, Construction 2025, industrial strategy: government and industry in partnership, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/210099/bis-13-955-construction-2025-industrial-strategy.pdf, (2013).
[17] E.R. Hoffer, Measuring the Value of BIM: Achieving Strategic ROI, Autodesk, Inc, 2014, https://damassets.autodesk.net/content/dam/autodesk/www/solutions/pdf/Is-it-Time-for-BIM-Achieving-Strategic-ROI-in-Your-Firm%20_ebook_BIM_final_200.pdf.
[18] D.T. Jamison, Cost-effectiveness analysis: Concepts and applications, in: R. Detels, R. Beaglehole, M.A. Lansang, M. Gulliford (Eds.), Oxford Textbook of Public Health, Oxford University Press, 20119780199218707.
[19] S.A. Jones, H.M. Bernstein, The Business Value of BIM for Construction in Major Global Markets: How Contractors around the World Are Driving Innovation with Building Information Modeling, McGraw Hill Construction, Bedford, MA, USA, 2014https://www.construction.com/toolkit/reports/bim-business-value-construction-global-markets.
[20] S.A. Jones, H.M. Bernstein, The Business Value of BIM for Infrastructure: Addressing America's Infrastructure Challenges with Collaboration and Technology, McGraw Hill Construction, Bedford, MA, USA, 2012http://images.autodesk.com/adsk/files/business_value_of_bim_for_infrastructure_smartmarket_report__2012.pdf.
[21] S.A. Jones, H.M. Bernstein, The Business Value of BIM for Owners, McGraw Hill Construction, Bedford, MA, USA, 2014.
[22] S.A. Jones, H.M. Bernstein, The Business Value of BIM in China, Dodge Data and Analytics, Research and Analytics, Bedford, MA, USA, 2015.
[23] S.A. Jones, H.M. Bernstein, The Business Value of BIM in North America, Multi-Year Trend Analysis and User Ratings (2007–2012), McGraw Hill Construction, Bedford, MA, USA, 2012.
[24] S.A. Jones, D. Laquidara-Carr, The Business Value of BIM for Infrastructure 2017, Dodge Data and Analytics, Research and Analytics, Bedford, MA, USA, 2017https://www.construction.com/toolkit/reports/the-business-value-of-BIM-for-infrastructure-2017.
[25] W. Jung, G. Lee, The status of BIM adoption on six continents, Int. J. Civil Environ. Struct. Constr. Architect. Eng. 9 (5) (2015) 512–516 https://waset.org/Publication/1000109.
[26] Y. Jung, M. Joo, Building information modelling (BIM) framework for practical implementation, Autom. Constr. 20 (2) (2011) 126–133, https://doi.org/10.1016/j.autcon.2010.09.010.
[27] M. Kagioglou, R. Cooper, G. Aouad, Performance management in construction: a conceptual framework, Constr. Manag. Econ. 19 (1) (2001) 85–95, https://doi.org/10.1080/01446190010003425.
[28] S. Kolarić, M. Vukomanović, M. Radujković, D. Pavlović, Perception of building information modeling within the Croatian construction industry, International Scientific Conference People, Buildings and Environment 2016 (PBE2016), Luhačovice, Czech Republic, 2016 http://www.fce.vutbr.cz/ekr/pbe/Proceedings/2016/001_16140.pdf.
[29] R.G. Kreider, J.I. Messner, The Uses of BIM: Classifying and Selecting BIM Uses, The Pennsylvania State University, University Park, PA, USA, 2013http://bim.psu.edu/uses/the_uses_of_bim.pdf.
[30] R.G. Kreider, J.I. Messner, The Uses of BIM: Classifying and Selecting BIM Uses, Version 0.9, The Pennsylvania State University, University Park, PA, USA, 2013https://www.bim.psu.edu/download/the_uses_of_bim.pdf.
[31] G. Lee, H.K. Park, J. Won, D3 city project — economic impact of BIM-assisted design validation, Autom. Constr. 22 (2012) 577–586, https://doi.org/10.1016/j.autcon.2011.12.003.
[32] J. Lee, G. Lee, S.A. Jones, The Business Value of BIM in South Korea, how Building Information Modeling Is Driving Positive Change in the South Korean Construction Industry, McGraw Hill Construction, Bedford, MA, USA, 2012http://big.yonsei.ac.kr/pdf/biglists/1.SmartMarket/9.SMR_2012_ENG.pdf.
[33] J. Li, L. Hou, X. Wang, J. Wang, J. Guo, S. Zhang, Y. Jiao, A project-based quantification of BIM benefits, Int. J. Adv. Robot. Syst. 11 (8) (2014) 123, https://doi.org/10.5772/58448.
[34] W. Lu, A. Fung, Y. Peng, C. Liang, S. Rowlinson, Cost-benefit analysis of building information modeling implementation in building projects through demystification of time-effort distribution curves, Build. Environ. 82 (2014) 317–327, https://doi.org/10.1016/j.buildenv.2014.08.030.
[35] G. Mayo, B. Giel, R.R.A. Issa, BIM Use and Requirements among Building Owners, Computing in Civil Engineering (2012), ASCE, Clearwater Beach, Florida, https://ascelibrary.org/doi/abs/10.1061/9780784412343.0044, 2012.
[36] D. Migilinskas, V. Popov, V. Juocevicius, L. Ustinovichius, The benefits, obstacles and problems of practical BIM implementation, Proc. Eng. 57 (2013) 767–774, https://doi.org/10.1016/j.proeng.2013.04.097.
[37] National Institute of Building Sciences, National BIM Guide for Owners, National Institute of Building Sciences, Washington, D.C., USA, 2017https://www.nibs.org/page/nbgo_form.
[38] National Institute of Building Sciences, National Building Information Modelling Standard, Version 1.0, Part 1: Overview, Principles and Methodologies, National Institute of Building Sciences, Washington, D.C., USA, 2007https://www.nationalbimstandard.org/nbims-us.
[39] K. Newton, N. Chileshe, Awareness, usage and benefits of building information modelling (BIM) adoption-the case of South Australian construction organizations, 28th Annual ARCOM Conference, Edinburgh, UK, 2012 http://www.arcom.ac.uk/-docs/proceedings/ar2012-0003-0012_Newton_Chileshe.pdf.
[40] T.D. Oesterreich, F. Teuteberg, Looking at the big picture of IS investment appraisal through the lens of systems theory: a system dynamics approach for understanding the economic impact of BIM, Comput. Ind. 99 (2018) 262–281, https://doi.org/10.1016/j.compind.2018.03.029.
[41] T. Omer, C.-L. Daniel, J.S. Mirosław, Performance evaluation of construction enterprise resource planning systems, J. Manag. Eng. 24 (4) (2008) 198–206, https://doi.org/10.1061/(ASCE)0742-597X(2008)24:4(198).
[42] P. Powell, Information technology evaluation: is it different? J. Oper. Res. Soc. 43 (1) (1992) 29–42, https://doi.org/10.2307/2583696.
[43] Project Management Institute, Construction Extension to the PMBOK® Guide, Project Management Institute, 2016 9781628251746.
[44] D.S. Remer, A.P. Nieto, A compendium and comparison of 25 project evaluation techniques. Part 1: net present value and rate of return methods, Int. J. Prod. Econ. 42 (1) (1995) 79–96, https://doi.org/10.1016/0925-5273(95)00104-2.
[45] A.X. Sancbez, W. Joske, Benefits dictionary, in: A.X. Sanchez, K.D. Hampson, S. Vaux (Eds.), Delivering Value with BIM: A Whole-of-Life Approach, Taylor & Francis, Oxon OX, UK, 2016(9781317313182).
[46] R. Santos, A.A. Costa, A. Grilo, Bibliometric analysis and review of building

information modelling literature published between 2005 and 2015, Autom. Constr. 80 (2017) 118–136, https://doi.org/10.1016/j.autcon.2017.03.005.
[47] R.G. Saxon, Growth through BIM, Construction Industry Council, London, UK, 2013http://cic.org.uk/download.php?f=growth-through-bim-final-1.pdf.
[48] W. Shou, J. Wang, X. Wang, H.Y. Chong, A comparative review of building information modelling implementation in building and infrastructure industries, Arch. Comput. Meth. Eng. 22 (2) (2015) 291–308, https://doi.org/10.1007/s11831-014-9125-9.
[49] P. Smith, BIM implementation – global strategies, Proc. Eng. 85 (2014) 482–492, https://doi.org/10.1016/j.proeng.2014.10.575.
[50] D.S. Staples, I. Wong, P.B. Seddon, Having expectations of information systems benefits that match received benefits: does it really matter? Inf. Manag. 40 (2) (2002) 115–131, https://doi.org/10.1016/S0378-7206(01)00138-0.
[51] B. Succar, Building information modelling framework: a research and delivery foundation for industry stakeholders, Autom. Constr. 18 (3) (2009) 357–375, https://doi.org/10.1016/j.autcon.2008.10.003.
[52] B. Succar, The Five Components of BIM Performance Measurement, CIB World Congress, 2010, http://www.academia.edu/download/31438749/The_Five_Components_of_BIM_Performance_Measurement.pdf.
[53] B. Succar, W. Sher, A. Williams, Measuring BIM performance: five metrics, Arch. Eng. Des. Manag. 8 (2) (2012) 120–142, https://doi.org/10.1080/17452007.2012.659506.
[54] The Computer Integrated Construction Research Group, BIM Project Execution Planning Guide, The Pennsylvania State University, University Park, PA, USA, 2011https://www.bim.psu.edu/bim_project_execution_planning_guide/bim-project-execution-planning-guide.html.
[55] S. Vass, An organizational perspective on the business value of BIM, Department of Real Estate and Construction Management, Royal Inst. Technol. (KTH) (2015), https://www.diva-portal.org/smash/get/diva2:874083/FULLTEXT01.pdf.
[56] V. Venkatesh, F.D. Davis, A theoretical extension of the technology acceptance model: four longitudinal field studies, Manag. Sci. 46 (2) (2000) 186–204, https://doi.org/10.1287/mnsc.46.2.186.11926.
[57] J. Ward, P. Taylor, P. Bond, Evaluation and realisation of IS/IT benefits: an empirical study of current practice, Eur. J. Inf. Syst. 4 (4) (1996) 214–225, https://doi.org/10.1057/ejis.1996.3.
[58] J.S. Wholey, Formative and summative evaluation: related issues in performance measurement, Eval. Pract. 17 (2) (1996) 145, https://doi.org/10.1177/109821409601700206.
[59] J. Won, G. Lee, How to tell if a BIM project is successful: a goal-driven approach, Autom. Constr. 69 (2016) 34–43, https://doi.org/10.1016/j.autcon.2016.05.022.
[60] J.-B. Yang, Implementing Building Information Modeling (BIM) Technique in Public Construction Works, Public Construction Commission Executive Yuan (PCC), Taiwan Taipei, 2017 978-986-05-1942-6 https://www.grb.gov.tw/search/planDetail?id=11924409&docId=494893.
[61] N.W. Young Jr., S.A. Jones, H.M. Bernstein, J.E. Gudgel, The Business Value of BIM, Getting Building Information Modeling to the Bottom Line, McGraw Hill Construction, Bedford, MA, USA, 2009http://images.autodesk.com/adsk/files/final_2009_bim_smartmarket_report.pdf.
[62] L. Zheng, W. Lu, K. Chen, K.W. Chau, Y. Niu, Benefit sharing for BIM implementation: tackling the moral hazard dilemma in inter-firm cooperation, Int. J. Proj. Manag. 35 (3) (2017) 393–405, https://doi.org/10.1016/j.ijproman.2017.01.006.