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Cost-benefit analysis of Building Information Modeling implementation in building projects through demystification of time-effort distribution curves

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ABSTRACT

With a view to legitimizing the adoption of Building Information Modeling (BIM) in the architecture, engineering, and construction (AEC) industry, researchers in recent years have endeavored to develop models that can be used to analyze the costs/benefits of its implementation. However, these models rely heavily on anecdotal evidence, guiding BIM users to identify costs/benefits item by item. As a result, the costs/benefits are too often underestimated or exaggerated. This paper adopts an alternative approach, aiming to measure BIM costs/benefits by demystifying the time-effort distribution curves of real-life AEC processes. Empirical data on two public housing projects – one with BIM implemented and the other without – are used to calculate the costs/benefits of BIM implementation. It is found that, when compared with the non-BIM project, BIM implementation increased the effort input at the design stage by 45.93% (which implies 100.9 HKD/m^2 increase in this study), but at the building stage decreased the cost per square meter of GFA by 8.61% (which indicates 591.76 HKD/m^2 saving in this study). Taking a holistic view of the AEC processes, BIM implementation contributed about a 6.92% cost saving (which means 490.86 HKD/m^2 saving in this study) to the sample BIM project. While these research findings can be used to justify the promotion of more widespread BIM adoption in the AEC industry, cost-benefit analysis (CBA) of BIM implementation remains hampered by a general lack of data.

1. Introduction

In recent years, the adoption of Building Information Modeling (BIM) in the architecture, engineering, and construction (AEC) industry has been widely advocated. According to Eastman et al. [1], BIM is a verb or an adjective phrase to describe tools, processes and technologies that are facilitated by digital, machine-readable documentation about a building, its performance, its planning, its construction and later its operation. Davies and Harty [2] elaborate that BIM has become a common nomenclature for the family of technologies and related practices used to represent and manage the information used for, and created by, the process of designing, constructing and operating buildings. The Academic Resource Center [3] at the Illinois Institute of Technology listed 30 BIM-related software tools that are frequently used by architects, engineers, and contractors. According to the AIA report on the Business of Architecture, about 60% of architecture firms in the US employing more than 50 people use some form of BIM; the equivalent figure for Finland is 93% according to the Finnish ICT Barometer [4]. A Smart Market Report by McGraw Hill Construction [5] surveyed BIM users and found that 62% use BIM on more than 30% of their projects. Further, it has been noted that some public building owners in the UK, US, Denmark, Finland, and Hong Kong are starting to demand the implementation of BIM in their projects [6–8].

BIM has been developed to facilitate the life-cycle management of buildings. For example, BIM has been used to improve the quality of design [9–11], to reduce construction cost and delay [12,13], to ameliorate facilitate management [14–16], and to facility AEC education in the universities [10,17,18]. Moreover, with performance metrics in BIM, it has also been promoted for building performance simulation at the design stage in order to achieve sustainability in

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the whole-life cycle [19]. For example, integrated with other tools, BIM can be used for sustainability assessment [20], energy analysis [21–25], estimating carbon emission [26–28]. However, as a life-cycle inventory, the performance of BIM implementation itself remains an unanswered question.

Running in parallel with BIM development is an inquiry into its benefits. This is a non-trivial issue; BIM adoption in the AEC industry needs legitimacy on the ground. To provide this legitimacy, researchers have endeavored to measure the costs/benefits contributed by this emerging technology. Barlish and Sullivan [29] identified 21 studies of this kind, not including the recent studies [9,10,12,13,30,31]. The major difficulty faced in these studies is that the costs/benefits of BIM are hard to disentangle and even more difficult to quantify. This is particularly true now given that BIM is being increasingly integrated into managerial aspects of AEC projects, such as improving communication and encouraging collaborative work. An exacerbating factor is that data on BIM implementation in the industry are not readily available. Therefore, existing measuring tools have been designed in a scorecard fashion, asking BIM users to report costs/benefits. These tools are useful in that they involve frontline BIM users and encourage them to examine costs/benefits comprehensively. However, the downside is that they rely mainly on anecdotal evidence and the subjective judgments of users. Too often, these self-reporting models underestimate or exaggerate the costs/benefits contributed by BIM. The resulting mixed perspectives and opinions on the benefits of BIM have created a general misunderstanding of its expected outcomes [28].

This paper aims to develop an analytical model to measure the costs/benefits of BIM implementation in AEC processes. The cost/benefit analysis (CBA) differs from previous models in that it is based on empirical secondary data recorded in real-life projects. The methodology of this research is largely inspired by the time-effort distribution curves introduced by MacLeamy [32]; by comparing the effort input in a BIM-supported construction project (hereinafter the BIM project) with that of a project without BIM support (hereinafter the non-BIM project), it is hoped that the costs/benefits of BIM can be properly measured. The rest of the paper is organized as follows. Section 2 is a critical review of the literature on measuring BIM costs/benefits, and Section 3 is a brief account of time-effort distribution curves. Methodology is described in Section 4, and the case studies are introduced in Section 5. Section 6 is an in-depth discussion of the analytic results. Section 7 concludes the paper and makes a recommendation for future research.

2. Cost-benefit analysis (CBA) of BIM implementation

From the outset, the development of BIM and inquiry into its costs/benefits have been inextricably linked. This is to be expected; if a technology initiation is to sustain in a competitive business world it must have a genuine economic foundation. In BIM adoption, research has shown that one of the major hurdles is justification of the additional cost using evident benefits [11]. Users who are to adopt BIM need the encouragement of empirical evidence, while investors need to discern clear proof of its benefits in order to justify their investment of time and budget [13]. From a broader perspective, this inquiry can be linked to an earlier line of research work measuring the contributions of technology to business performance [33–35]. However, measurement of the costs/benefits of BIM has its own idiosyncrasies which present unique challenges to researchers.

The first challenge is to understand the reasons for adopting BIM. The construction industry is often accused of low productivity. The main culprit is construction being a fragmented industry adopting a flawed design-bid-building (DBB) procurement system. Under this system, the client typically signs separate contracts with the architect, engineer, and contractor; parties who do not always work together efficiently and can, in fact, have competing interests [31]. The construction industry needs better communication, integration, and collaboration based on information interoperability [5,11,36,37]. BIM is envisaged to be a promising solution to these problems, and thus a means of increasing productivity.

The second challenge is to recognize the benefits of BIM. As shown in Table 1, previous studies have thoroughly explored the benefits of BIM implementation, which include, *inter alia*, better communication, early collaboration, error-free design, less rework, better predictability, saved cost, and improved productivity [11,12,30–32]. However, current measuring methods are cumbersome in terms of disentangling the portion of costs/benefits contributed by the adoption of BIM. For example, clash detection is often used as an example for mainstreaming BIM adoption in the AEC industry; the opportunity cost that a clash take place without being detected by BIM is often estimated and attributed to BIM as one of its benefits. But increasingly, hands-on engineers believe such attribution exaggerates the benefits of BIM as they are also able to use their experience to detect a clash. More challenging in terms of recognizing the benefits of BIM is that it is used in managerial aspects of AEC processes such as improving communication, encouraging collaboration, and facilitating knowledge sharing. It is in these “soft” areas that BIM can have a more profound impact [32]. However, this impact is indirect and difficult to isolate.

The third challenge is that the data required to measure the costs/benefits of BIM implementation in the AEC industry are not usually accessible. Researchers tend to use anecdotal evidence to support claims of the benefits of BIM, while scant empirical studies have been reported. As shown in Table 1, researchers tend to deploy case studies which are, by and large, controlled experimental environments; real AEC processes are influenced by many random factors such as the weather, site conditions, and users' attitudes towards BIM. The dearth of reliable data also makes it difficult to engage rigorous mathematical methods (e.g. econometrics models using time-serial data) that can help alleviate the influence of random factors.

In view of the drawbacks of existing measurement methods, the aim of this research is to develop a model that can be used to measure both tangible and intangible costs/benefits of BIM implementation in real-life AEC processes. The model must be “inclusive” enough to recognize overall BIM costs/benefits while offsetting the random factors that impact real-life BIM implementation. One means of minimizing these factors, as suggested by Barlish and Sullivan [29], is to examine different projects of the same organization. Ideally the model should also not, by its nature, be greedy for data. In our search for such a model, we found promise in MacLeamy's time-effort distribution curve.

3. The time-effort distribution curve

As shown in Fig. 1, MacLeamy's [32] time-effort distribution curve comprises four components: (1) a curve indicating ability to impact cost and functional capability as a project progresses; (2) a curve showing the cost of design change; (3) a curve indicating the design effort distribution in traditional AEC processes; and (4) a curve showing the distribution of design effort in BIM-enabled AEC processes. Traditional AEC processes in the DBB procurement system involve separate efforts from designers and contractors mainly invested in construction documentation and management (Curve 3), while BIM-enabled processes encourage more effort (e.g. early collaboration and open information sharing) from the entire project team during the schematic design and design development phases (Curve 4). MacLeamy [32] argues that BIM implementation should advance design effort to the schematic design and design

Table 1
A list of typical studies in measuring BIM's benefits.

Benefits of BIM	Stage	Methodology	Conclusions	Reference
(1) Inspiration of novel design; (2) design error detection; (3) construction plan rehearsal and optimization; (4) detection of unsafe areas; (5) construction site management; (6) construction communication; (7) project information and knowledge management; and (8) reduction of creeping managerialism.	Design and Building	A triangulated methodology including literature review, field works, case studies, open debates and interviews.		Li et al. (2009)
(1) Improved engineering design quality (e.g. error-free drawings); (2) Improved labor productivity	Design	Case studies	BIM unequivocally improves the quality of precast engineering design, in terms of accuracy and reliability of the documents.	Kaner et al. (2008)
Saved project cost for precast concrete companies	Building	Case studies	Saving a range of 2.3–4.2 percent of total project cost for precast concrete companies	Sacks et al. (2005)
Increased productivity in structural engineering design	Design	A benchmark for two series of experiments in structural engineering practice	An increase of productivity ranging from 15% to 41% for cast-in-place reinforced concrete structures in the drawing phase	Sacks and Barak (2008)
Improved quality, on time completion and units per man-hour	Design and Building	Questionnaire survey		Patrick and Raja (2007)
Saved cost and potential delays	Building	Case studies	Save an estimated $600,000 in extras and avoid months of potential delays	Azhar et al. (2008)
(1) Elimination of unbudgeted change; (2) Increased cost estimation accuracy; (3) Reduced time for cost estimation; and (4) Saving contract value and (5) reduction in project time.	Design and Building	Case studies	Up to 40% elimination of unbudgeted change, a cost estimation accuracy within 3%, up to 80% reduction in time taken to generate a cost estimate, a saving of up to 10% of the contract value and up to 7% reduction in project time.	CIFE (2007)
Improved pedagogy of architecture, engineering, and construction in universities or colleges.	Education	Experiments, etc.		Dennis (2006, 2007); Ibrahim and Rahimian, (2010); Peterson et al. (2011); Sacks and Barak, (2010); Hedges and Denzer (2008)
Saved construction cost	Building	The learning curve, mathematic modeling, and case studies	BIM can be used as a learning tool for real-life construction works	Lu et al. (2013)

development phases, as increased effort at these phases will alleviate the ingrained problems associated with the DBB system and lead to improved execution of a construction project. Owing to its intuitiveness, MacLeamy's set of curves has been widely cited by researchers as an illustration of how BIM can bring benefits to construction projects [13].

Time-effort distribution curves also offer methodological implications for the measurement of overall costs/benefits of BIM implementation in construction projects. The area enclosed by Curve 3, the horizontal axis and the vertical axis can be perceived as the overall effort in undertaking a project using traditional AEC processes. Likewise, the area enclosed by Curve 4, the horizontal axis and the vertical axis represent the overall effort in undertaking the project with BIM implemented. Subtraction of the two areas represents the saved effort contributed by BIM implementation. Using mathematical language, this rationale can be expressed in Equation (1).

$$\int f(x4)\mathrm{d}x - \int f(x3)\mathrm{d}x = \text{BIM's benefits} \quad (1)$$

where $f(x3)$ and $f(x4)$ stand for Curves 3 and 4 respectively, and the indefinite integrals stand for the areas enclosed by Curves 3/4, the horizontal axis and the vertical axis (graphically shown in Fig. 1). Since the time-effort distribution curve is easy to show BIM's benefits during the AEC process, this study devises the methodology on the basis of this rationale.

4. Methodology

The detailed methodology of this study is illustrated in Fig. 2.

4.1. Step 1: collecting data from multiple projects to produce the time-effort distribution curves

Collecting data from real-life construction projects is often difficult. Owing to their one-off, irreversible nature, it is often difficult and/or too expensive to study them in a comparative experiment which involves, e.g. setting up treatment and control groups and deriving experimental data. The temporary nature of project teams further complicates data collection. In this research, two real-life projects, one with BIM implemented and the other without, need to be found as cases to scrutinize whether there is any difference in the time-effort distribution curves resulting from BIM implementation. Ideally, two identical projects with only the factor of BIM implementation distinguishing them would be found for comparison. In real construction practice, however, variables

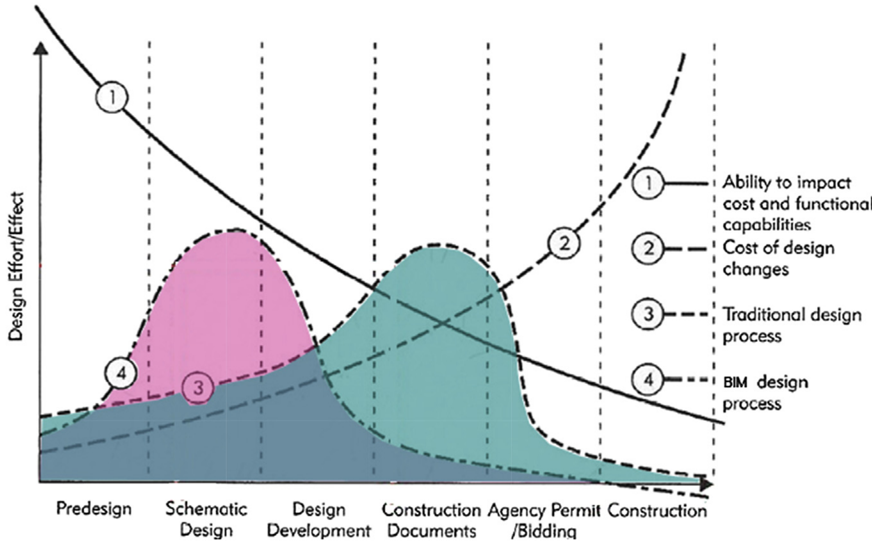

Fig. 1. The time-effort distribution between BIM-enabled and traditional AEC processes.
Source: Adapted from MacLeamy (2004)

such as project type, site logistic plan, project manager leadership, and worker craftsmanship make every site unique. Thus, stringent research efforts should be made to reduce this uniqueness so that the two projects are comparable, if not entirely identical.

In addition, it is critical to articulate the terms “time” and “effort” before any sensible data collection strategy can be devised. Lu et al. [13] suggest that the term “time” means time period during a project process (e.g. daily, weekly or monthly intervals), and “effort” is the amount of chargeable time rendered by individual participants in the project. They further argue that the chargeable time cannot simply be aggregated, as different professionals will charge different fees for the efforts they render. Instead, Lu et al. [13] introduce the term “priced efforts (PE)” to incorporate differences in efforts that have been priced through market mechanisms such as competitive bidding and tendering. In this research, the bar chart vehicle shown in Fig. 3 was designed to capture the effort contributed to a project by individual participants. Using this method, the data for input effort can be collected through analysis of payment records, even after a project has been completed.

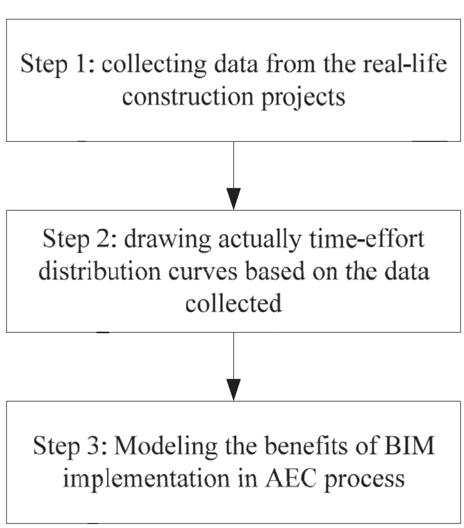

Fig. 2. The working flow of modeling BIM's costs/benefits in construction projects based on the time-effort distribution curves.

As a result of Step 1, two sets of time-effort data will be collected. They can be defined in mathematical language as shown in Equations (2) and (3).

$$E = \{\mathrm{PE}_1,\ \mathrm{PE}_2,\ \mathrm{PE}_3, \ldots, \mathrm{PE}_T\} \tag{2}$$

$$E' = \{\ \mathrm{PE}'_1,\ \mathrm{PE}'_2,\ \mathrm{PE}'_3, \ldots, \mathrm{PE}'_t\} \tag{3}$$

where PE_j represents all the input priced efforts in time j. E is the set of priced efforts data for the BIM project and T is the corresponding time point; while E' denotes the set of priced efforts data for the non-BIM, and t is the relevant time point. By vertically aggregating the priced efforts as recorded in Equations (2) and (3), and linking the data points, a time-effort distribution curve can be drawn.

4.2. Step 2: data processing and drawing the actual time-effort distribution curves

The priced efforts as shown in Equations (2) and (3) need to be processed further in order to draw the actual time-effort distribution curves. Construction projects usually have different site conditions, gross floor area (GFA), contract sums, procurement models, start dates, and so on. Thus, it is necessary to “normalize” the two datasets to reduce the impact of these factors so that the datasets are comparable. The first step in this normalization is to discount the difference in GFA of the two projects. This is achieved by dividing the two datasets in Equations (2) and (3) with the GFA of the respective projects. Second, the impact of inflation should be deducted as the two projects may differ in start date and duration. By setting the earliest date as the baseline, the inflation index of each time point can be found and discounted. The two sets of normalized priced efforts resulting from Step 2 are shown in Equations (4) and (5).

$$\begin{aligned} E &= \{\mathrm{EN}_1,\ \mathrm{EN}_2,\ \mathrm{EN}_3, \ldots, \mathrm{EN}_T\} \\ &= \{\mathrm{PE}_1/(\mathrm{GFA}\times \mathrm{CPI}_1),\ \mathrm{PE}_2/(\mathrm{GFA}\times \mathrm{CPI}_2), \\ &\quad \mathrm{PE}_3/(\mathrm{GFA}\times \mathrm{CPI}_3), \ldots, \mathrm{PE}_T/(\mathrm{GFA}\times \mathrm{CPI}_T)\} \end{aligned} \tag{4}$$

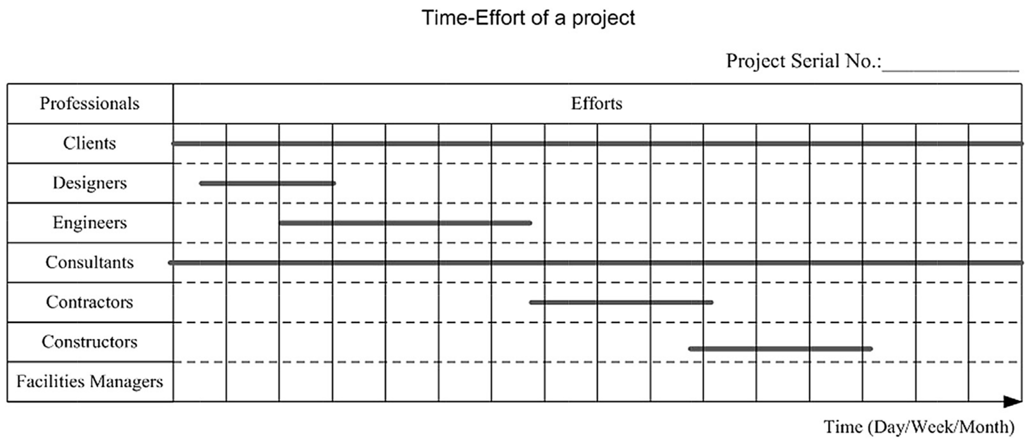

Fig. 3. An innovative approach to capture a time-effort distribution curve for a project.

$$\begin{aligned}\mathrm{EN}' &= \{\mathrm{EN}'_1,\ \mathrm{EN}'_2,\ \mathrm{EN}'_3,\ldots,\mathrm{EN}'_t\}\\ &= \{\mathrm{PE}'_1/(\mathrm{GFA}'\times\mathrm{CPI}'_1),\ \mathrm{PE}'_2/(\mathrm{GFA}'\times\mathrm{CPI}'_2),\\ &\quad \mathrm{PE}'_3/(\mathrm{GFA}'\times\mathrm{CPI}'_3),\ldots,\mathrm{PE}'_t/(\mathrm{GFA}'\times\mathrm{CPI}'_t)\}\end{aligned} \tag{5}$$

where EN is the set of normalized priced efforts data for the BIM project, GFA is the corresponding gross floor area, T is the corresponding time point, and CPI_T is the inflation index compared to the baseline at the time point T; while EN' denotes the set of normalized priced efforts data for the non-BIM project, GFA' is the corresponding gross floor area, t is relevant time point, and CPI'_t is the inflation index compared to the baseline at the time point t. One can perceive the normalized priced efforts as the overall effort input to construct each unit of GFA.

4.3. Step 3: modeling the costs/benefits of BIM implementation in AEC processes

Based on the rationale shown in Equation (1), the basic approach for modeling the costs/benefits of BIM implementation is to find the variation between input effort in the BIM project and input effort in the non-BIM project. However, data collected from real-life projects are largely discrete, which does not allow for generation of a precise and continuous curve. Thus, still following the rationale, this paper uses the accumulation of the discrete data rather than the indefinite integral as shown in Equation (1) to measure costs/benefits. The measurement equation is shown in Equation (6).

$$k = \frac{\sum \mathrm{EN}'_t - \sum \mathrm{EN}_t}{\sum \mathrm{EN}'_t}\times 100\% \tag{6}$$

where k implies the percentage of saved normalized priced efforts brought about by BIM implementation in the comparison period, $\Sigma\mathrm{EN}_T$ is the accumulated normalized priced efforts input into the BIM project during the comparison period, while $\sum \mathrm{EN}'_t$ is the normalized priced efforts in the non-BIM project accumulated in the comparison period.

In order to investigate how BIM implementation brings costs/benefits to specific architecture, engineering, and construction processes, this paper divides projects into two stages: pre-building and building. The pre-building or design stage can be considered to include inception, feasibility study, design, engineering and bid or, in other words, the architecture (A) and engineering (E) processes, while the building stage is the construction (C) process. Therefore, Equation (6) can be further developed to measure the benefits brought about by BIM at the design stage, building stage and the whole lifecycle of the project as shown in Equations (7)–(9).

$$k_p = \frac{\sum_1^{\mathrm{Pre}} \mathrm{EN}'_t - \sum_1^{\mathrm{Pre}} \mathrm{EN}_T}{\sum_1^{\mathrm{Pre}} \mathrm{EN}'_t}\times 100\% \tag{7}$$

$$k_b = \frac{\sum_{\mathrm{Pre}}^{\mathrm{Bui}} \mathrm{EN}'_t - \sum_{\mathrm{Pre}}^{\mathrm{Bui}} \mathrm{EN}_T}{\sum_{\mathrm{Pre}}^{\mathrm{Bui}} \mathrm{EN}'_t}\times 100\% \tag{8}$$

$$k_w = \frac{\sum_1^{\mathrm{Bui}} \mathrm{EN}'_t - \sum_1^{\mathrm{Bui}} \mathrm{EN}_T}{\sum_1^{\mathrm{Bui}} \mathrm{EN}'_t}\times 100\% \tag{9}$$

where k_p, k_b, k_w is the percentage of saved normalized priced efforts brought about by BIM implementation at the design stage, building stage and throughout the whole project lifecycle, respectively. Pre is the time point when the project completes its design stage, and Bui is the time point at which the project completes its building work and is ready for operation.

5. Case studies

5.1. Sample

Two public rental housing (PRH) projects in Hong Kong – one with BIM implemented and the other without – were selected as the sample for this study. Basic information on the two projects was collected from the Hong Kong Housing Authority (HKHA) and is summarized in Table 2. The HKHA is a statutory body which develops and implements Hong Kong's public housing programme. Approximately 30% of the Hong Kong population currently resides in public rental housing units, and public housing expenditure as at 2012 was HKD80 billion [38]. To achieve economies of scale, PRH developments in Hong Kong often adopt similar models. As shown in Fig. 4, the buildings of the two projects have similar complexity overall. Both projects selected for this study are high-rise non-standard domestic buildings. The main frameworks were constructed using cast in-situ technologies while the rest, such as the slabs, walls, façade, and kitchens used precast technologies. Both adopted a traditional design, bid, and build (DBB) procurement model. Considering that foundation parts are often more unpredictable in construction, only the building parts are considered in this study. Although the two projects are broadly similar, further consideration has been given to making them more comparable. For example, the tree transplantation efforts in the BIM project, and

Table 2
Basic information of the researched housing projects.

	Non-BIM project	BIM project
Location/District	Cheung Sha Wan, Kowloon	Wong Tai Sin, Kowloon
Type of building	Non-standard domestic building	Non-standard domestic building
Contract sum (Foundation stage, HK$m)	102.343	Unknown
Contract sum (Building Stage, HK$m)	505.300	384
Gross site area (m^2)	10,188	12,000
Gross floor area (m^2)	53,184	42,480
Starting date	February 2007	September 2008
Design stage	August 2009	June 2010
Progress	Completed	Accomplished 85%
completion date	May 2013	Continuing

the efforts of demolishing the existing buildings in the non-BIM project are disregarded. In addition, the non-BIM project has an ancillary facility block while the BIM project does not; the non-BIM project's gross floor area (GFA) and the relevant efforts are therefore deducted. The BIM project has witnessed BIM implementation in some critical aspects throughout the AEC processes, while the non-BIM project was delivered with no BIM elements involved. The BIM project is ongoing and was 85% complete when the data were collected while the non-BIM project was 100% complete at data collection.

Three sets of data were collected: (1) a series of monthly interim payments made to the related parties/professionals; (2) Gantt charts indicating different AEC stages; and (3) a series of timesheets recording the major efforts contributed by the client (the HKHA) to the two projects. The interim payment was recorded by HKHA strictly according to the progress, which therefore reflects all relevant incurred costs at the recorded time. To draw a full picture of the time-effort distribution based on the three datasets, an understanding of how the HKHA undertakes housing projects is required. The HKHA maintains various in-house teams to conduct design, engineering, surveying, procurement, bidding, supervision and other professional work, while construction is mainly tendered out to contractors. In implementing BIM, the HKHA has developed an in-house BIM center to keep abreast of BIM developments around the world. The development of the BIM model itself is tendered out to BIM service providers, who are normally hired by the main contractor on a separate contract. With this implementation model, the HKHA acts as both a client and a designer. In contrast to traditional projects, the HKHA does not make interim payments to designers (in this case, the in-house professional teams) but they receive salaries. Dataset (3) provides a detailed elaboration of efforts spent on a project by the in-house team. Although the team is within the HKHA as a statutory body, it actually operates based on market mechanism; efforts were recorded and priced, similar to other commercial companies do. By combining datasets (1) and (3), the overall efforts spent on a project by both the in-house team and the contractor can be comprehensively examined, while the Gantt charts can be used to understand how the efforts were spent over time and most importantly to judge the time point of design stage and building stage.

5.2. General analysis

With February 2007 set as the baseline, the inflation index at each month up to May 2013 was calculated using the CPI released by the Census and Statistics Department of the Hong Kong Government. By following the normalization processes described in Step 2, the priced efforts of the two projects were normalized with the relevant GFA and inflation index. By plotting the normalized efforts in the two-dimensional coordinate system, the time-effort distribution curves of the two projects were derived, as shown in Figs. 5 and 6.

The descriptive statistics of the normalized time-effort data illustrate the general trends of the normalized time-efforts of the two projects (see Table 3). Given that the BIM project was just 85% complete and the non-BIM project was 100% complete at the time of data collection, measurement of the benefits of BIM is best achieved by following Equations (7)–(9) as developed above, rather than by direct comparison of the mean or median value of the two projects.

(a) Buildings of the BIM project (b) Buildings of the non-BIM project

Fig. 4. The buildings of the BIM and non-BIM projects in the case study.
Source: Google Earth

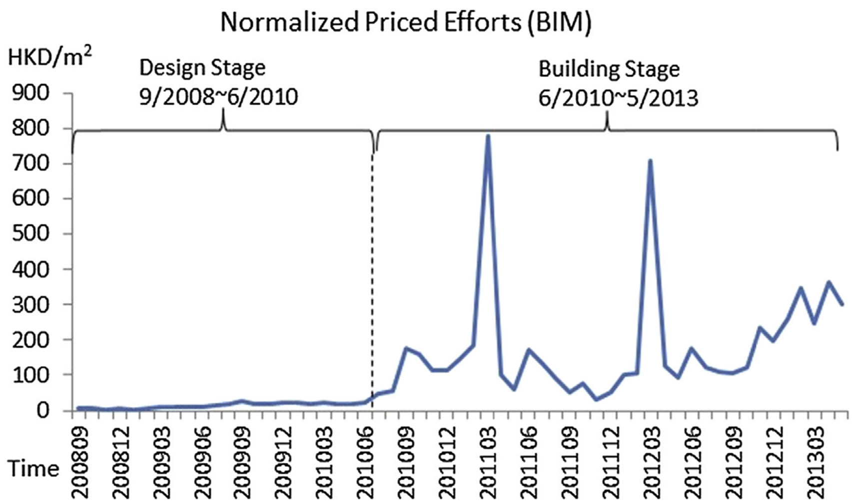

Fig. 5. Plotted data of normalized priced efforts of the BIM project.

5.3. Overall costs/benefits of BIM implementation

By following Equations (7)–(9), the costs/benefits contributed by BIM at the design, building, and whole project stages can be calculated. The design stage of the BIM project started in September 2008 and ended in June 2010, while that of the non-BIM project started in February 2007 and was completed in August 2009. By substituting the variables in Equation (7) with the collected data, the benefits of BIM at the design stage can be calculated as shown in Equation (10).

$$k_p = \frac{\sum_{200702}^{200908} \mathrm{EN}'_t - \sum_{200809}^{201006} \mathrm{EN}_T}{\sum_{200702}^{200908} \mathrm{EN}'_t} \times 100\% = \frac{219.69 - 320.59}{219.69} \times 100\% = -45.93\% \quad (10)$$

For the building stage, it must be taken into account that the BIM project was just 85% complete while the non-BIM project was 100% complete at the time of data collection. Therefore, for consistency, the examined period for the non-BIM project is 85% instead of 100% according to the time schedule. This is meaningful as the monthly interim payment reflects the construction progress and the incurred cost at the recorded time point. Thus, for the building stage, the BIM project started in July 2010 and ended in May 2013 (85% completed), while the non-BIM project started in September 2009 and ended in June 2012 (85% completed). By substituting the variables in Equation (8) with the collected data, the benefits of BIM at the building stage (85%) can be obtained as shown in Equation (11).

$$k_b = \frac{\sum_{200909}^{201206} \mathrm{EN}'_t - \sum_{201007}^{201305} \mathrm{EN}_T}{\sum_{200909}^{201206} \mathrm{EN}'_t} \times 100\% = \frac{6869.37 - 6277.61}{6869.37} \times 100\% = 8.61\% \quad (11)$$

From a whole project point of view, the BIM project started in September 2008 and ended in May 2013 (85% completed), while the non-BIM project started in February 2007 and ended in June 2012 (85% completed). By substituting the variables in Equation (9) with the collected data, the benefits of BIM at the whole project stage (85% of the project) can be calculated as shown in Equation (12).

$$k_w = \frac{\sum_{200702}^{201206} \mathrm{EN}'_t - \sum_{200809}^{201305} \mathrm{EN}_T}{\sum_{200702}^{201206} \mathrm{EN}'_t} \times 100\% = \frac{7089.06 - 6598.2}{7089.06} \times 100\% = 6.92\% \quad (12)$$

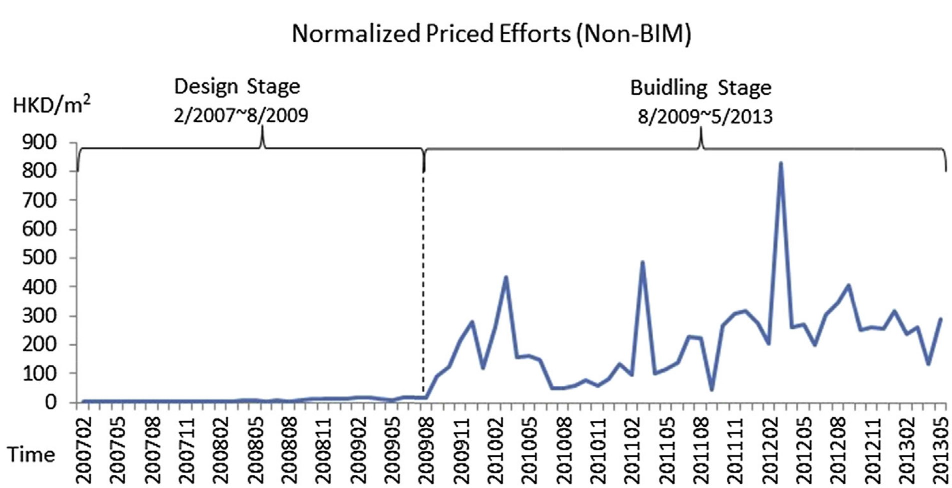

Fig. 6. Plotted data of normalized priced efforts of the non-BIM project.

Table 3
Descriptive statistics of the normalized priced efforts (HKD/m^2).

Project	BIM project	Non-BIM project
Mean	115.7579	133.5407
Median	77.8200	88.1000
S.D.	150.7152	151.4851
Kurtosis	9.468	4.595
Skewness	2.793	1.667
Range	775.79	827.94
Number of data	57	76

As shown in Fig. 7, it was found that, at design stage, the cost per square meter of the BIM project increased 45.93% when compared with that of the non-BIM project. This can be attributed to the fact that BIM implementation requires extra initial upfront investment and incurs operation cost in software, hardware and expertise. The design team also needs to undergo a learning curve to adapt to this new approach in architecture and engineering processes. This increased cost at design stage is, however, rapidly offset by the benefits of BIM implementation at the building stage. As shown in Equation (11), the cost per square meter of the BIM project decreased 8.61% when compared with that of the non-BIM project, even though only 85% of project completion was examined. Bearing in mind that the physical building stage involves much larger effort input (e.g. material, labor and plant), an 8.61% saving (which indicates 591.76 HKD/m^2 saving in this study) at the building stage is actually much larger than the 45.93% expenditure increase (which implies 100.9 HKD/m^2 increase in this study) at the design stage. MacLeamy [32] suggests that in the manufacturing industry it is generally accepted that costs increase ten-fold in the transition from design to procurement to fabrication. On examination of the entire AEC process, BIM implementation in the BIM project brought about a 6.92% cost saving per square meter (which means 490.86 HKD/m^2 saving in this study) when compared to the non-BIM project.

5.4. *Client's costs/benefits of using BIM*

The above section outlines the overall costs/benefits brought about by BIM implementation and offers a justification for the implementation of BIM in the construction industry. Nevertheless, project clients, especially private ones, are usually alleged to have little motivation to push forward BIM implementation in practice, viewing BIM as just an expensive fad. This section further investigates the costs/benefits from a client's perspective, with a view to justifying BIM implementation at the client's initiative.

In this investigation, a similar analytical process to that shown in the above section is adopted, but with only the in-house priced efforts recorded in the timesheets considered. Table 4 illustrates the general trend of the normalized time-efforts of the two projects. In addition, the distribution of in-house normalized priced efforts of the BIM and non-BIM projects were derived, as shown in Figs. 8 and 9.

By following Equations (7)–(9), the costs/benefits contributed by BIM to the client at the design, building, and whole project stage were calculated. For the design stage, the BIM project started in September 2008 and ended in June 2010, while the non-BIM project started in February 2007 and ended in August 2009. By substituting the variables in Equation (7) with the normalized in-house priced efforts, the costs/benefits of BIM implementation to the client at the design stage can be obtained as shown in Equation (13).

$$k'_p = \frac{\sum_{200702}^{200908} EN'_{inhouse-t} - \sum_{200809}^{201006} EN_{inhouse-T}}{\sum_{200702}^{200908} EN'_{inhouse-t}} \times 100\%$$
$$= \frac{219.69 - 320.59}{219.69} \times 100\% = -45.93\% \quad (13)$$

For the building stage, again, it should be noted that the BIM project was just 85% complete while the non-BIM project was 100% complete when the data were collected. Therefore, for consistency, the cutoff period for examining the projects is 85% instead of 100% completion. Thus, the building stage for the BIM project started in July 2010 and ended in May 2013 (85% completed), while the building stage for the non-BIM project started in September 2009 and ended in June 2012 (85% completed). By substituting the variables in Equation (8) with the collected data, the costs/benefits of BIM for the client at the building stage (85%) can be obtained as shown in Equation (14).

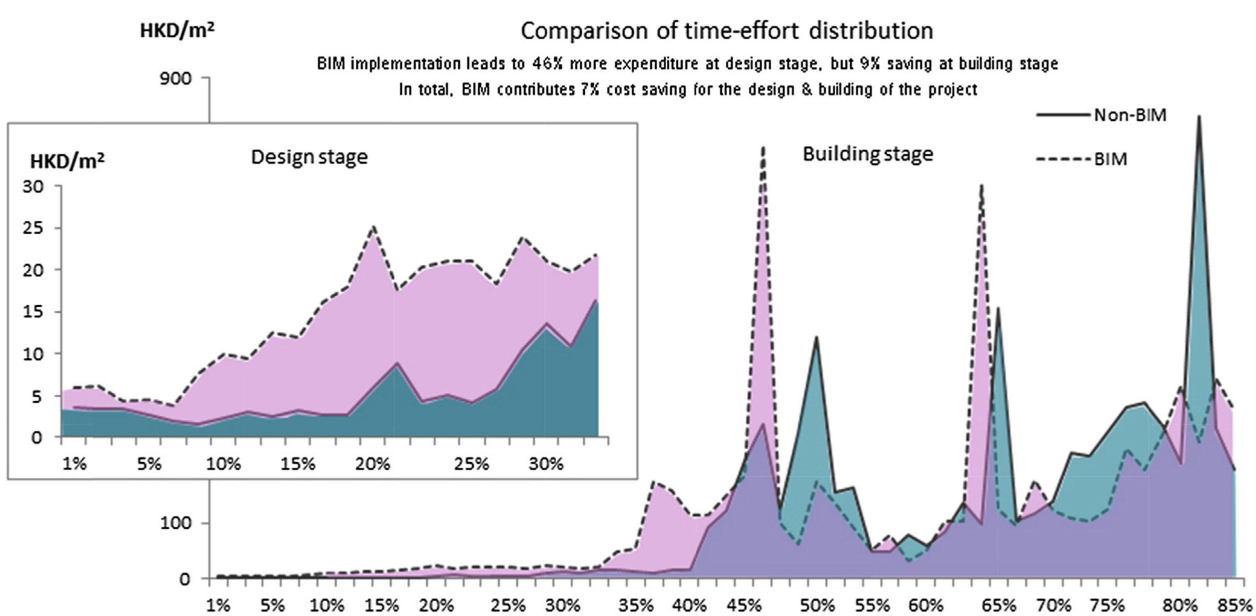

Fig. 7. A graphic summary of cost-benefit analysis of BIM implementation in AEC processes.

Table 4
Descriptive statistics of the in-house normalized priced efforts (HKD/m^2).

Project	BIM project	Non-BIM project
Mean	21.3858	15.1863
Median	21.6600	17.4150
S.D.	8.59959	8.08946
Kurtosis	0.894	−1.008
Skewness	0.119	−0.381
Range	42.63	28.47
Number of data	57	76

$$k'_b = \frac{\sum_{200909}^{201206} \mathrm{EN}'_{\mathrm{inhouse}-t} - \sum_{201007}^{201305} \mathrm{EN}_{\mathrm{inhouse}-T}}{\sum_{200909}^{201206} \mathrm{EN}'_{\mathrm{inhouse}-t}} \times 100\% = \frac{739.73 - 898.4}{739.73} \times 100\% = -21.45\% \quad (14)$$

From a whole project point of view, the BIM project started in September 2008 and ended in May 2013 (85% completed), while the non-BIM project started in February 2007 and ended in June 2012 (85% completed). By substituting the variables in Equation (9) with the collected data, the costs/benefits of BIM for the client at the whole project stage can be obtained as shown in Equation (15).

$$k'_w = \frac{\sum_{200702}^{201206} \mathrm{EN}'_{\mathrm{inhouse}-t} - \sum_{200809}^{201305} \mathrm{EN}_{\mathrm{inhouse}-T}}{\sum_{200702}^{201206} \mathrm{EN}'_{\mathrm{inhouse}-t}} \times 100\% = \frac{959.42 - 1218.99}{959.42} \times 100\% = -27.05\% \quad (15)$$

The results show that, at design stage, the in-house cost contributed by the client to the BIM project increased 45.93% (which implies 100.9 HKD/m^2 increase in this study) when compared to that of the non-BIM project. This is the same as the analytic result presented in Equation (10); at design stage, only the HKHA's in-house efforts were involved. As shown in Equation (14), in-house efforts contributed by the client to the BIM project at building stage increased 21.45% (which indicates 158.67 HKD/m^2 increase in this study) when compared with those of the non-BIM project when 85% of project completion is examined. In total, BIM implementation brought the client around a 27.05% in-house cost increase per square meter (which means 259.57 HKD/m^2 increase in this study) compared with that of the non-BIM project when 85% of project completion is examined.

6. Discussion

BIM implementation in AEC processes does incur extra cost. This includes initial capital investment in hardware and BIM software licenses, and operation cost in updating hardware and software, as well as developing domain knowledge. In addition, BIM implementation inevitably alters traditional AEC processes. Normally, for an individual project, a site resident BIM team including client, designer and consultant members will be set up to refine the design, answer the request for information (RFI), consider design changes, and so on. All members will need to experience learning curves. Moreover, it is widely noticed that the resistance from the organization or individual usually presents difficulties of using new methods or technologies in the construction sector [39–41]. It is thus not surprising to find that, in the two sample projects, BIM implementation brought to the client about a 27.05% in-house cost increase when compared to the non-BIM implemented project. The increased cost, as noted by a director of a BIM center in a private company, could be as high as HKD10 million a year. Researchers have reported that this additional cost is one of the major obstacles to widespread adoption of BIM in the construction industry [11]. However, it should be noticed that the improved building performance through optimizing the design with BIM would further save costs at the facilitate management stage [23,25,42]. This saved costs would be a major justification for the client to adopt BIM, however, which are not analyzed due to lack of data. In addition, the clear demonstration of BIM's benefits would also facilitate the individual and organization to better understand BIM, and further reduce the resistance to change [43].

Nevertheless, the increased cost brought about by BIM implementation at the design stage of a project can be offset by the benefits it brings at the building stage. In the two sample projects, BIM implementation contributed about 6.92% or 490.86 HKD cost saving per square meter to the BIM project when compared to the non-BIM project. This study is thus probably the first of its kind to articulate the interactive relationship of the costs/benefits of BIM at the design and building stages of a project. The findings of this study can be used to justify promotion of wider BIM adoption in the AEC industry as a means of alleviating its problems such as low productivity, backwardness, silo thinking, fragmentation and discontinuity. To a certain extent, the study proves MacLeamy's [32] theoretical argument that a slight increasing in effort spent at the design stage through BIM implementation will significantly improve overall project performance.

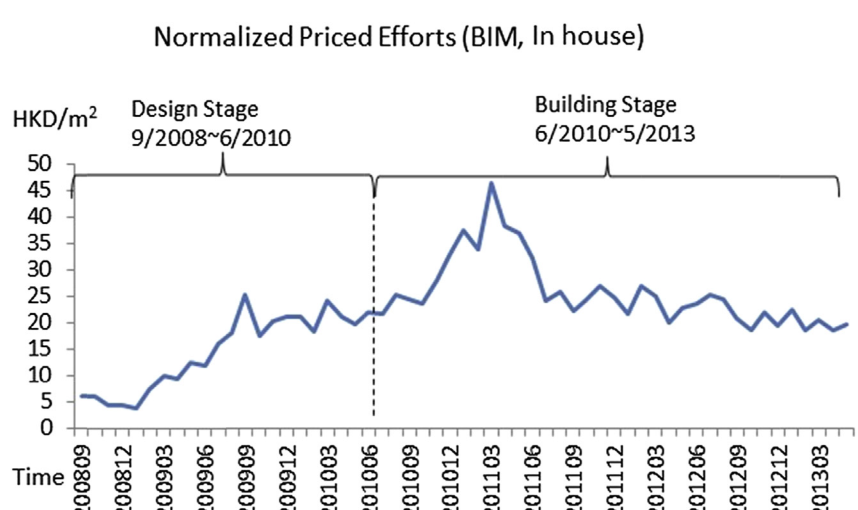

Fig. 8. Plotted data of in-house normalized priced efforts of the BIM project.

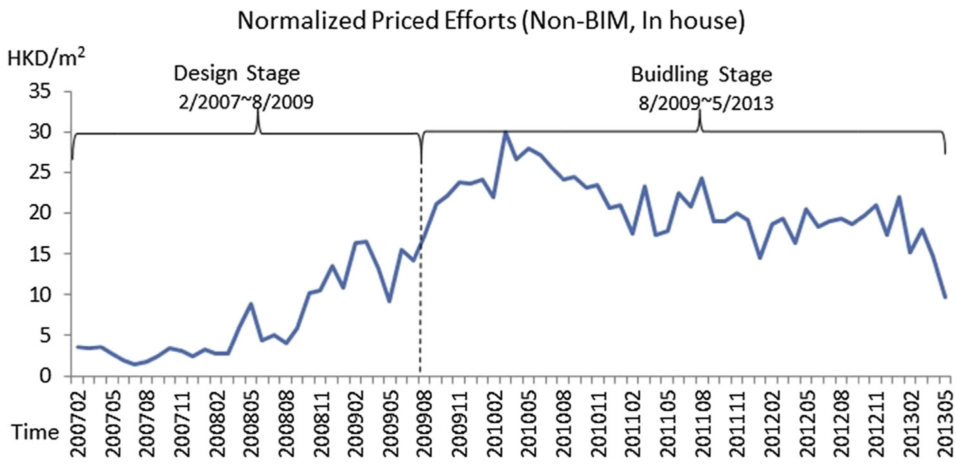

Fig. 9. Plotted data of in-house normalized priced efforts of the non-BIM project.

The changing costs/benefits pattern articulated in this study gives rise to other issues that are critical to BIM implementation. A key area of contention is how costs and benefits are shared amongst stakeholders. According to one view, the client is a beneficiary of BIM implementation and should thus be responsible for the extra cost. Indeed, in the above cases, the client (HKHA) is willing to pay for the extra cost of BIM implementation. Following Aranda-Mena et al.'s [44] suggestion that a clear understanding of the time-effort distribution curve would have direct implications for the variation of fee structures, Lu et al. [13] further argue that fee structures throughout AEC processes should be adjusted for BIM implementation. This assertion resonates with research attempting to develop an economic framework for analyzing the incentive problems associated with BIM implementation [45,46].

The costs/benefits analysis in this study applies some methodological innovations. Firstly, in contrast to previous subjective measurements of BIM costs and benefits, this research is grounded in secondary empirical data collected from real-life construction projects. In addition, the use of actual time-effort distribution curves based on payment records and a bar chart vehicle for cost-benefit analysis is an original methodology which has other research applications. The time-effort distribution curves are also a useful graphical tool for examining the cost-benefit patterns of BIM-implemented projects.

Similar research has been conducted in other economies, with higher or lower costs/benefits being reported. While the research findings from this study could be used as a basis for comparison, it must be emphasized that the findings are derived from a relatively small sample and so cannot justifiably be generalized, even to other projects of the HKHA. Although substantial attention has been paid to increasing the comparability of the two sample projects, there are factors that might not have been considered. Therefore, the cost-benefit analysis carries with it a level of uncertainty and the results should be viewed in this light. Nevertheless, it is believed that the cost-benefit analysis contained in this paper reflects the best data currently available.

7. Conclusions

This paper pioneers the use of time-effort distribution curves to evaluate the costs/benefits of BIM implementation in construction projects. It is found from the two sample housing projects that BIM implementation increased by 45.93% or 100.9 HKD the effort input per square meter of GFA at the design stage of a project. At the building stage, however, the cost per square meter of GFA of the BIM project decreased 8.61% or 591.76 HKD/m^2 when compared to that of the non-BIM project. From a holistic perspective of AEC processes, BIM implementation contributed about 6.92% or 490.86 HKD cost saving per square meter to the sample BIM project. The research not only measures the costs/benefits of BIM implementation, but also, to a certain extent, substantiates the argument that a slight increase in effort at the design stage through BIM implementation will significantly improve the execution of a construction project overall. This cost-benefit analysis can therefore be used to justify the encouragement of wider BIM adoption in the AEC industry.

The research adopts innovative approaches to produce the time-effort distribution curves and to conduct the cost-benefit analysis. These approaches make good use of the data currently available for two sample projects. Nevertheless, the analysis is hampered by a general lack of data, given that data collection in BIM projects is still sporadic in the industry. As the two samples are limited, it is recognized that the cost-benefit analysis carries with it some level of uncertainty. The results should be viewed in this light. Further studies are recommended to conduct the cost-benefit analysis in other real-life BIM implementation cases and to explore their implications. In addition, it is worthwhile to investigating the time-effort distribution at the inception and feasibility stage, as BIM is said to bring benefits due to early stakeholder engagement. Moreover, as a life-cycle inventory, the cost-benefit analysis of BIM should be expanded to the facilitate management stage in future studies.

Acknowledgment

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