Demystifying the time-effort distribution curves in construction projects: a BIM and non-BIM comparison

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ABSTRACT

MacLeamy proposed a set of time-effort distribution curves, with a view to mainstreaming the adoption of Building Information Modeling (BIM) in the architecture, engineering, and construction (AEC) industry. Numerous researchers and practitioners have cited these curves, but no previous research has ever endeavored to draw actual time-effort distribution curves and analyze them. The aim of this paper is to introduce a novel approach to draw real-life time-effort distribution curves and understand their implications. A data collection form is developed in this paper to record the efforts contributed to a project by various parties. The time-effort distribution curve can be drawn by using both data plotting and mathematical curve fitting. Two public housing projects, one with BIM support while the other without BIM involved, were adopted in this paper for drawing the real-life time-efforts distribution curves. It is found that the time-effort distribution curves in real-life projects are of little similarity to those reported by MacLeamy.

INTRODUCTION

The rise of Building Information Modeling (BIM) in the construction industry in recent years is probably one of the most remarkable phenomena that have interested business executives, managers, professionals, and policy-makers. According to Eastman (1999), BIM is “a digital representation of the building process used to facilitate the exchange and interoperability of information in digital format”. The Academic Resource Center (2012) at Illinois Institute of Technology listed 30 BIM related software tools that are frequently used by architects, engineers, and the like. It is generally agreed that BIM is a revolutionary technology and process that has quickly transformed the way buildings are conceived, designed, constructed and operated (Hardin, 2009). BIM has even been credited with bringing about a paradigm shift in the architecture, engineering, and construction (AEC) industry (Lu and Li, 2011).

However, BIM has not been adopted without hesitation. This is evident by various cost/benefit analyses being undertaken with a view to mainstreaming BIM adoption in the industry (Sacks et al. 2005; Sacks and Barak 2008; CIFE 2007; Barlish and Sullivan 2012; Lu et al. 2013). Nevertheless, how BIM can take effect
still remains a question to BIM practitioners and researchers. Amongst the many
efforts to understand how BIM functions, MacLeamy (2008) attributed the problems
in the industry to a fatally flawed system; under the current design, bid, and build
(DBB) system, professionals such as architects, engineers, surveyors, and contractors
are separately contracted to do a parcel of the work. As such, they do not always work
together efficiently and, in fact, can have competing interests (MacLeamy, 2008).
This silo mentality is a well-known aspect of the fragmentation and discontinuity in
the AEC industry (Egan, 1998; Lu and Li, 2011).

With the help of his time-effort distribution curves (See Figure 1), MacLeamy
illustrates how these issues can be addressed through implementation of BIM in AEC
processes. Traditional AEC processes in the DBB procurement system involve the
investment of separate efforts by designers and contractors 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 argues that BIM implementation should advance design effort to the
schematic design and design development phases, and that this slight change will
ameliorate the ingrained problems associated with the DBB system and lead to
productivity improvement.

Figure 1 Time-effort distribution between BIM-enabled and traditional AEC
processes (adapted from MacLeamy 2008)

Owing to its intuitiveness, many researchers have used MacLeamy’s set of
curves to illustrate the benefits of BIM with a view to mainstreaming its
implementation in the AEC industry. However, to the best of our knowledge, no
research has yet been conducted to elaborate the time-effort distribution curve of a
construction project. Nor has previous research been undertaken to produce an actual
time-effort distribution curve. While Aranda-Mena et al. (2009) present two
interesting versions of MacLeamy’s theoretical curves, their approach is largely
qualitative; they solicited quality responses to the perceived “effort distribution”
required to create BIM.

The aim of this research is therefore to demystify the time-effort distribution
curves of a construction project with BIM support (hereinafter the BIM project) by comparing them with the curves of a construction project without BIM support (hereinafter the non-BIM project). Subsequent to this introductory section, the research methodology is introduced in Section 2. Here, a set of innovative approaches devised to produce the time-effort distribution curve of a project from time sheets and payment records are described. Case studies of two housing projects, one with BIM implementation and the other without a BIM element, are introduced in Section 3, and a thorough discussion of the analytic results is conducted. Section 4 further explores the implications of the time-effort distribution curves for management practice, while Section 5 draws conclusions and proposes directions for further research.

METHODOLOGY

The detailed methodology of this study is in two manifolds: (a) Collecting data and producing the time-effort distribution curves from real-life projects, and (b) Fitting and fine-tune the time-effort distribution curves using rigorous methods.

Step 1: Collecting data and producing the time-effort distribution curves from real-life projects

Here “time” means time period during a project process. It could be day, week, or even month intervals, depending on how detail one would research into the project process. Research has reported the term “effort” in the AEC industry. In undertaking a project, different participants such as clients, architects, consultants, contractors, other professionals, and labor will input their efforts throughout the different stages of the project. On the surface, the effort is the amount of “chargeable time” rendered by individual professionals. Based on this understanding, we designed a bar chart vehicle for capturing efforts contributed to a project (see Figure 2[a]). By vertically aggregating the efforts as recorded in Figure 2(a) and linking the data points, a time-effort distribution curve can be drawn (See Figure 2[b]).

The efforts cannot simply be measured, as different professionals will charge different fees for the efforts they rendered. Even more complicated, Smith and Tardif (2009) argued that the “calendar time” is much harder to determine. A proxy of the efforts is the interim payment made by the client to different parties. In so doing, it is possible to collect the data of the input efforts in Figure 2(a). Here we introduce a “priced efforts (PE)” as shown in Matrix (1):

\[
P_E = \begin{bmatrix} PE_{11} & \cdots & PE_{1n} \\ \vdots & \ddots & \vdots \\ PE_{m1} & \cdots & PE_{mn} \end{bmatrix}
\]  

(1)

where \(PE_{ij}\) represents the priced efforts from party \(i\) in time \(j\). By vertically aggregating the PE, or as shown in \(V_j = \sum_{i=1}^{m} PE_{ij}\), and linking the data points, a time-effort distribution curve can be derived. Two sets of time-effort data will be collected. They can be defined in mathematical language as shown in Equations (2) and (3).
where \( E \) 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 relevant time point.

\[
E = \{PE_1, PE_2, PE_3, \ldots, PE_n\} \\
E' = \{PE'_1, PE'_2, PE'_3, \ldots, PE'_n\}
\]

Figure 2. Process from a matrix of time-effort to a time-effort distribution curve for a project

Step 2: Data processing through normalization

In order to compare time-effort distribution curves in BIM and non-BIM projects, the two projects ideally should be identical to allow for a meaningful comparison. Yet, in the real world, it is hardly possible to find two such projects due to many factors such as a project manager’s leadership, and workers’ craftsmanship, making any project a unique one. In view of these, one may select similar projects from the same company to allow them having the same organizational culture, working capability, and so on. However, construction projects should have different site conditions, gross floor area (GFA), contract sum, procurement models, starting dates, and so forth. As such, it is necessary to “normalize” the two data sets to reduce the impact from random factors and to make them comparable. One simple way to normalize the data is to consider the efforts consuming on each unit construction floor area of the corresponding project, which is the result of each entry \( PE_j \) of (2) and (3) dividing the corresponding GFA of the project respectively, given that all these data removing the impact of inflation. In summary, the normalization procedure could be termed in the equation (4) and (5):
where $EN$ denotes the set of normalized priced efforts data for the BIM project, $GFA$ is the corresponding gross floor area, $T$ is the 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 the time point, and $CPI_t$ is the inflation index compared to the baseline at the time point $t$.

In addition, projects may not only start from different time, but also see different project durations. In order to make the projects comparable, the time point mentioned above should be also normalized. One common way to do so is to transfer the time point to the percentage of project completion (PPC) at that time point, which thus ranges from 0% to 100%. That is to divide the specific time point with the project duration. By linking the normalized data of time and effort, we can transform Equations (4) and (5) to the following equations.

$$ENN = \left( \frac{PE_{i/L}}{GFA' \times CPI_{i/L}} \right)$$
$$ENN' = \left( \frac{PE_{i/L}}{GFA' \times CPI_{i/L}} \right)$$

where $ENN$ is the data set of normalized time-effort for the BIM project and $T/L$ is its PPC, while $ENN'$ denotes the data set of normalized time-effort for the non-BIM project and $t/l$ is its PPC. From on now, further analysis will be based on datasets as shown in Equations (6) and (7) rather than in Equations (2) and (3).

**Step 3: Depicting the time-effort distribution curves**

With normalized time-effort data, the distribution curves of a project can be depicted in the two-dimensional coordinate system for further analyses. Firstly, the time-effort distribution curves generated from the real-life projects can be compared with the theoretical curves proposed by MacLeamy (2008). In addition, the pattern of increased or saved efforts can be revealed by the time-effort distribution curves by comparing them between the BIM and non-BIM projects. Implications from the real-life time-effort distribution curves can further be explored, i.e., how they can inform the relevant stakeholders to implement BIM better.

**CASE STUDY**

**Data samples**

Two public housing projects (BIM and non-BIM project) in Hong Kong were selected for the empirical case study. Basic information of the two projects is summarized in Table 1. Both projects are high-rise, non-standard domestic buildings. The main frameworks of the projects were constructed by using cast in-situ technologies while the rest, such as slab, walls, façade, kitchens, used precast
technologies. Both adopted a traditional design, bid, and build (DBB) procurement model. They were both located in Kowloon, Hong Kong, such that they have similar site conditions to conduct the AEC processes. Both projects were developed by the Hong Kong Housing Authority (HKHA), as the government executive arm responsible for public housing development in Hong Kong. The BIM project has witnessed BIM implementation throughout the AEC processes, although in some critical aspects only, e.g. clash detection, simulation of construction sequence, etc. The non-BIM project, as its name indicated, is procured without any BIM element involved. One noteworthy point is that the BIM-project was still on-going, with 85% being accomplished when the data was collected in May 2013, while the non-BIM project has been completed in that month.

| Table 1. Basic information of the researched housing projects |
|-----------------|---------------------------|---------------------------|
| **Location/District** | BIM project | Non-BIM project |
| Kowloon | Kowloon |
| **Type of Building** | Non-standard domestic building | Non-standard domestic building |
| **Contract Sum (Foundation stage, HK$m)** | Not available | 102,343 |
| **Contract Sum (Building Stage, HK$m)** | 384 | 505.3 |
| **Gross Floor Area (m²)** | 42,480 | 53,184 |
| **Starting Date** | September 2008 | February 2007 |
| **Progress** | Accomplished 85% in May 2013 | Completed in May 2013 |

**Data processing**

By following Step 1 as described in the methodology section, we used the innovative data collection vehicle (Fig. 3) to collect the priced efforts of the two projects. Next in Step 2, the datasets were normalized by dividing the efforts with GFA and CPI. The BIM project was started in September 2008, and it has undergone 57 months with 85% completed. The non-BIM project was started in February 2007, and it has lasted for 76 months before its full completion in May 2013. The priced efforts mainly have two parts: one is the time sheet created by HKHA when its in-house design teams undertook various tasks such as schematic design, engineering, and tendering, and the other is the interim payment made by HKHA to external stakeholders such as contractors and consultants. The priced efforts of the two projects in each month were obtained by aggregating the in-house payment and the interim payment in each month.

By setting February 2007 as the baseline, the inflation index in each month was calculated by using the CPI index released by the Census and Statistics Department of Hong Kong Government. By following the methods as described in Step 2, the priced efforts of the two projects were normalized with the respective GFA and the CPI. In addition, the time data of the two projects was also normalized by following the approaches as described in Step 2.
Depicting the time-effort distribution curves

By using the normalized time-effort data, the time-effort distribution curves of the non-BIM and the BIM project are produced, as shown in Figures 3 and 4. This is a process to link the normalized effort data points and plot them in the two-dimensional coordinate system. The vertical axis is the effort spent on each unit of the floor area (unit: HKD/m²) and the horizontal axis is the progress of the project ranging from 0% to 100%. To better understand how the efforts were distributed in AEC processes, the curves have been produced by dividing the processes into two stages: pre-building stage and building stage. One can perceive the pre-building stage as including inception, feasibility study, foundation, design, engineering, and bidding, or in other word, the architecture (A) and engineering (E) processes, while the building stage in Figures 3 and 4 the construction (C) process. Through interviewing the project managers, we found that the pre-building stage of the BIM project was from September 2008 to June 2010 while that was from February 2007 to August 2009 for the non-BIM project.

![Figure 3. Plotted time-effort distribution curve of the BIM project](image)

ANALYSES, FINDINGS AND DISCUSSIONS

General observations of the time-effort distribution curves

In both Figures 3 and 4, there are many spikes on the curves; the later the project stage, the more spikes one can see. This is attributed to the payment system prevailing in the construction industry. Contractors are paid in arrears; normally at the end of one month, an interim payment will be arranged to a contractor to reimburse the works that have been undertaken by the contractor. One may also observe that the curves at the pre-building stage in both projects are quite flat, if comparing them with their counterparts at building stage. Indeed, the efforts spent on design stage are often minuscule, if comparing them with the efforts spent on the physical construction stage later on, which often involves huge material, labour, and plant input. By putting
the two parts of efforts in the same two-dimensional coordinate system, it comes as no surprise that the curves at the pre-building stage are flat and close to the zero point.

Figure 4. Plotted time-effort distribution curve of the non-BIM project

At this juncture, it needs to emphasize that MacLeamy (2008), in his curves, emphasizes design efforts only and suggests how a small change of design efforts can make a significant difference in the overall project. However, a closer look at the design effort distribution curves at the pre-building stage does not yield any sense of similarity between the actual curves and MacLeamy’s theoretical curves. This requires us to put the two curves on design efforts in the same two-dimensional coordinate system for comparison.

Comparing the actual and theoretical time-effort distribution curves at A&E processes

Figure 5 shows the actual time-effort distribution curves of the real-life BIM and non-BIM projects at their design stage. The smaller scale in the vertical axis makes the curves more contrasting to allow for better comparisons. It can be seen from Figure 5 that the first peak of normalized effort for the BIM project is 25.2 HKD/m² at PPC of 19%, the second is 24.02 HKD/m² at 28%, and the third is 21.84 HKD/m² at 33%. The normalized design effort curve for the BIM project begins to decrease after it reaches the first peak at 19%, although it still has two lower peaks after that. By contrast, there are four peaks of the normalized design effort curve for the non-BIM project: the fourth is 8.9 HKD/m² at 21%, the third is 13.56 HKD/m² at 30%, the second is 16.53 HKD/m² at 34%, and the first is 17.21 HKD/m² at 41%. The value of the normalized effort for the non-BIM project increases with PPC and reaches its peak at the end of pre-building stage. Although the curves in Fig. 6 are not as smooth as MacLeamy (2008)’s theoretical curves (Fig. 1), which may be a result of noise and the discrete form of the data, they do vividly show that the effort peak was shifted to an earlier stage with BIM implementation. Therefore, the theoretical
time-effort distribution curves proposed by MacLeamy (2008) were supported by the two real-life cases.

Figure 5. The time-effort distribution curve of BIM and non-BIM projects at the design stage

CONCLUSIONS

Much has been said about the time-effort distribution curves coined by MacLeamy, but little has been done to demystify them using real-life cases. By adopting a series of innovative approach, this study produced the actual time-effort distribution curves and compared them between a BIM project and a non-BIM project. This study proves that BIM implementation does incur extra expenses at the design stage but the expenses will pay off at the construction stage later on. For the first time, the theoretical time-effort distribution curves proposed by MacLeamy were substantiated by the two real-life cases in this study. MacLeamy’s theoretical suggestion that spending a bit more design effort will make a significant difference in the overall project performance is also supported by the two cases.

Implications arisen from the time-effort distribution curves were put forward for advancing BIM adoption in architecture, engineering, and construction processes. The finding from this study, to a certain extent, supports the argument that the fee structure should be skewed to the design stage to fully exploit BIM’s functionalities. Yet, BIM implementation does not necessarily prolong the design stage. Instead, it can shorten the design stage by providing a useful platform for pondering design options, early involvement of all team members, and open information sharing. This finding encourages users to adopt BIM more confidently. The time-effort distribution curves are found a handy graphical tool in examining the cost/benefit patterns, and the strengths/weaknesses underlying a BIM implementation model. Further studies are recommended to draw the curves in more real-life BIM implementation cases and explore their implications.
REFERENCES