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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