Using Effort Distribution Analysis to Evaluate the Performance of Building Information Modeling Process

A.A. Aibinu[1], P. de jong[2], H. Wamelink[3] and A. Koutamanis[4]

[1] Faculty of Architecture, Building and Planning, The University of Melbourne, VIC 3010, Australia; aaibinu@unimelb.edu.au
[2]Faculty of Architecture and the Built Environment, Delft University of Technology, Netherlands; P.deJong@tudelft.nl
[3]Faculty of Architecture and the Built Environment, Delft University of Technology, Netherlands; j.w.f.wamelink@tudelft.nl
[4]Faculty of Architecture and the Built Environment, Delft University of Technology, Netherlands. a.koutamanis@tudelft.nl

ABSTRACT

Adopters of BIM need to find the most appropriate implementation strategy that is economically efficient for their organization in order to achieve satisfactory organizational and project outcomes. This paper explores why and how the distribution of effort spent on various project activities over a project's life cycle can be used at both project and organizational levels as one of the metrics for evaluating, benchmarking and improving the performance of BIM implementation process. Using a case study, it explores how project time accounting data can be used to visualize and analyze effort distribution pattern. The findings shows the benefit of BIM effort distribution. Based on the visualization, unusual distribution of efforts can be identified and organizations can understand the productivity of their processes. The unusual effort distribution alert can support root-cause analysis process to identify and correct the root causes. On that basis, corrective and preventive actions can be implemented, and BIM process can be improved. The analysis of effort distribution can also help organizations compare BIM projects with non-BIM projects. It can be used to manage cash flow, and to structure fees and support return on investment analysis. Effort distribution analysis can increase project participants' understanding of project dynamics from a resource allocation perspective.

INTRODUCTION

Lack of full team integration can make construction project information difficult to generate, transmit, reuse, coordinate and managed. In the traditional procurement, where project phases progresses in a linear sequence, information are often recreated by various parties during the different stages of the project life cycle thereby leading to duplication of efforts, waste, inefficiency, low productivity, project delays and cost blowout. With Building Information Modeling (BIM), a building can be represented in a digital, computable and intelligent 3D form (model). All information needed to realize the building can be stored in the model. The information can be shared in a quick and efficient manner. The input from the various design disciplines, contractors, suppliers and subcontractors can be sought early in the design process; and potential problems e.g clashes and buildability issues can be resolved thereby eliminating potential delays during construction and can result in better building. Thus BIM is a radical innovation because it fundamentally changes the way information about buildings are represented as well as the way they are communicated, manipulated, and shared. There is some evidence to suggest that BIM adoption is on the growing increase (McGraw-Hill Construction 2012). Being a new way of working, BIM implementation represents organization change and a learning curve for users both at organizational and project levels. There is not yet a single best practice BIM adoption process and there may never be one. While there are practice guides for setting up a BIM management plan, adopters of BIM need to find the most appropriate implementation process that maximize the benefit for their organization and for projects. This involves performance measurement, benchmarking, learning, and improvement over time. Assessing the performance of BIM process can help adopters differentiate an efficient process from inefficient ones. It should also help them identify productivity gains to justify organizational change to BIM. Metrics and methods for measuring BIM performance are still evolving. Thus this study will contribute to BIM concept and practice. The objective is to describe how time accounting data can be used to visualize effort distribution over BIM process life cycle; and how it can be analyzed to assess the performance of BIM. Effort distribution is important because the benefit of BIM enabled project delivery lies in the way effort is distributed among the various project activities over the project life cycle. Unusual effort distribution could signal process inefficiencies, and form the basis for implementing improvement measures.

EFFORT DISTRIBUTION AND BIM PERFORMANCE - A CONCEPTUAL FRAMEWORK

This study is about the use of effort distribution analysis as a means of assessing the performance of BIM process. We will now conceptualize the term ‘effort’ and its impact on process efficiency and BIM project performance.

What is Effort? Work effort can be broadly defined as the amount of attentional resources that a person expends toward job tasks (Yeo and Neal 2004). It can be described in terms of consistency, persistence, and intensity of individuals to completing some tasks (Campbell 1990). Ergonomists and industrial engineers defined effort in terms of work output variables such as motions used, time elapsed, fatigue factors, weight, distances and amount of materials handled (Fleishman et al. 1984). In this study, we conceive ‘effort’ as time elapsed i.e. staff hours expended on a task or activity. In the field of software engineering, ‘effort’ data has been identified as the most useful data for assessing the validity of schedules, costs, quality, etc. of new projects by which new projects can be compared against similar projects (Jones 2004). In BIM, the benefit of measuring effort using ‘man-hours’ is that it can be linked to employee budget and fee structure.

Effort Distribution, Efficiency and BIM Process Performance. Effort distribution analysis have been applied in the field of software engineering (Heijstek and Chaudron 2007; Heijstek and Chaudron 2008). ‘Capability maturity model integration’ (CMMI) was developed by Software Engineering Institute (SEI) of the Carnegie Melon University. Levels 4 and 5 of the CMMI are a level of maturity where the process is quantitatively managed in accordance with agreed-upon metrics. Studies have found that there is a relationship between how an organization spends its time (effort) and productivity of their process (Scacchi 1995). For example, it has been discovered that the more time software companies spend in coding and testing the lower the software productivity and quality rates. Effort expended during BIM project life cycle can be an indicator of process efficiency or inefficiency because project activities are generally human intensive, knowledge intensive, and with many repetitive tasks. Thus work effort should be a plausible metric when measuring BIM performance. Also, there is a relationship between effort distribution and project outcomes. MacCleamy (2012) asserts that buildings are too expensive, don’t perform well and don’t last. He suggested that construction industry need a new strategy to shift more effort to design and away from other tasks. BIM can make this shift possible. MacCleamy proposed the effort curve which compares the time-effort distribution of traditional and integrated project process. The curve gives a good conceptual insight into the relationship between effort, project phase and time, and their impact on project outcomes. In an integrated project, increased effort during the early stages of project development can move design decisions upstream where they are more effective and less costly. The curve illustrates the concept of early design decision-making when opportunity to influence positive outcomes can be maximized and the cost of changes is minimized, especially as regards the designer and design consultant roles (AIA 2007). The concept also means that key project participants are involved from the earliest practicable moment. Decision-making is improved by the influx of knowledge and expertise of all key participants. Thus with BIM, project can be defined and coordinated to a much higher level before the commencement of construction on site. This can lead to time savings. For example, the more effort spent on coordination of different models (i.e. MEP, architectural and structural) can reduce clashes. Where they occur, they can be resolved early instead of left unattended until during construction when they become disruptive to project progress. The implementation of BIM does not reduce design and planning efforts. Instead, it should improve the outcomes by streamlining and shortening the much more expensive stage of project development (AIA 2007). It is possible that the savings envisaged by MacCleamy may not be achieved in a BIM-based integrated project delivery for many reasons: (1) inadequate modeling and coordination effort at the early stage (2) late involvement of key disciplines, suppliers and subcontractors. The effect is that problems may arise during the construction stage as a result of inaccurate models. This may lead many request for information (RFI), and changes. In the end, BIM-enabled project may be as expensive as the traditional project delivery if efforts spent on the various project activities is not appropriately distributed and managed over project’s life cycle. Based on these conceptualizations, it is reasonable to assume that the distribution of effort among the various activities over the phases of BIM-based project would influence project outcomes and organizational outcomes. It can be hypothesized that the ratio of the effort spent on project activities occurring at the early project stage would impact on number of defects, number of clashes in design, number of RFI, number of changes, and thereby project cost, time and quality performance. There has been relatively little research exploring the application of effort distribution to BIM assessment. In a study, Aranda-Mena et al. (2009) explored the differences in effort distribution curves between traditional and BIM-enabled projects using qualitative analysis of respondents' perceptions instead of a quantitative measure of actual effort. A visual representation of respondents' views shows inconsistencies in the respondents' perception of effort distribution in traditional project delivery method. Respondents believed that effort distribution curve for traditional method is evenly distributed between schematic design phase and detailed design phase rather than at the later stage of the project. Aranda-Mena et al. did not identify any consensuses. They concluded that a single model of effort distribution was not plausible. It may be argued that quantitative analysis of actual effort data could provide better insight. Based on analysis of real life projects, it may be possible to organize the effort distribution into clusters. This study contributes to research and practice in this area by describing how effort distribution can be explored to measure BIM performance.

EFFORT DISTRIBUTION – DATA REQUIREMENT AND ANALYSIS

Following previous studies in software engineering, we propose the use of 'person hours' (or man hours) expended on a project activity or a task as a measure of effort at one time. In order to preserve the confidentiality of the raw data, the absolute man-hours can be normalized for each data point by expressing efforts in the form of $\frac{\text{man hours}}{\text{total project hours}}$. We propose a visual representation of the time-effort data in the form bar or line chart as method for understanding effort distribution. The chart can depict the movement of effort over project life cycle. Unusual peak and movement can be investigated. Context information can be used to identify problem issues and areas for process improvement.

EFFORT DISTRIBUTION – FINDINGS FROM A CASE STUDY

In this paper, we use a real world BIM project (hereafter referred to as Project A) to show how effort distribution analysis might be applied to assess the performance of BIM process on a project. Due to space limitation, the analysis presented here is limited to 2 aspects: (1) effort distribution for the case study at the project level – i.e when data for all project activities are aggregated (2) Effort distributions for 'Working Drawings' activities. Effort distribution for quantity take-off, cost estimating, modeling, drafting/drawing and project management activities etc are not presented here. About 300 data points were used for the analysis. The data was based on the contractor's time accounting data. Specific project phases have also not been indicated in the analysis. Future study will incorporate this information. This is not expected to invalidate the study since visualization of effort distribution over the project time gives insight into the project dynamics.

Total Effort Distribution Visualization for Project 'A'. 'Project A' was awarded to the contractor after 'level of development 200' (LOD200). The contractor decided to use BIM as a process and platform for coordinating several subcontractors models to achieve LOD300, LOD400 and working drawings prior to construction. Figure 1 shows the total effort distribution for all activities including modeling, quantity take-off, cost estimating, drafting/drawing activities, project management, etc. Figure 1 shows that the overall BIM process effort expended on Project A started slowly and rapidly grew and peaked early in the process around 21% - 35% of the time between LOD200 and the completion of working drawing.

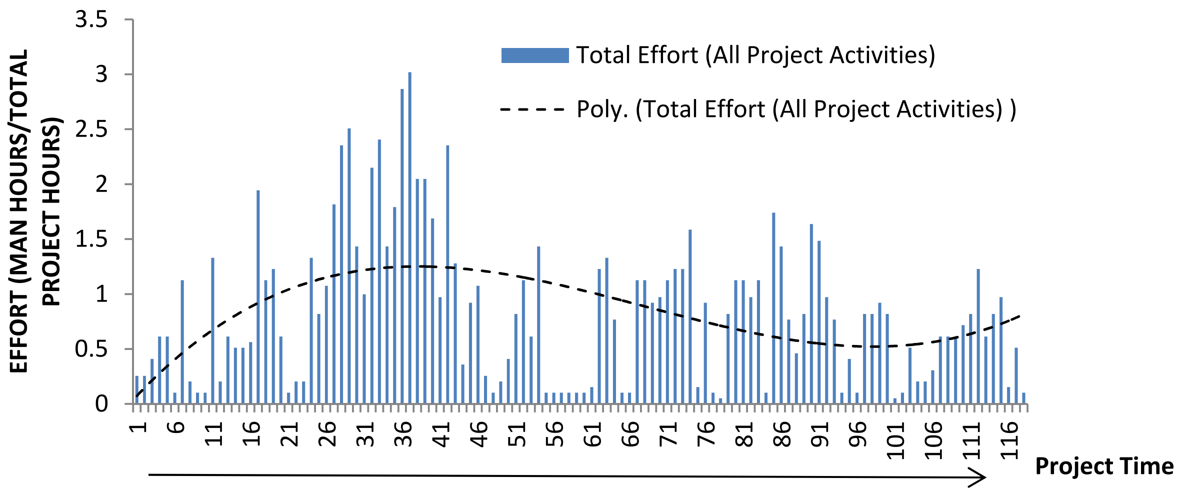

Figure 1. Effort distribution visualization for Project 'A'.

A further investigation shows that the slow beginning represents mostly project management effort and some quantity take-off efforts. Project management activities included exchange of documents among the various parties, preparation and agreement on BIM execution plan, and other project commencement coordination activities. The rapid built-up and peaked effort between 21% - 35% of the time represent effort expended on activities such as 3D modeling and drawing activities needed to bring the model to LOD300. Thus the slow and then rapid growth and peaked effort is not unexpected. Figure 1 also shows a second intense level of effort between 55% and completion of working drawing. This comprised of intense project management and working drawing activities involving the coordination of 3D models of several subcontractors to realize LOD400, as well as modeling activities including, clash detection, and revision to LOD400. It is not clear what is responsible for the sharp drop in total effort midway into the time.

Figure 2 shows the cumulative effort distribution fitted with polynomial trend line and plotted based in % of total effort and % of time. The polynomial trend of the cumulative effort distribution curve suggests that the initial stage the BIM process absorbed a lower level of effort which is equivalent to the initial project management activities. As the project approaches the start of LOD 300, more effort was absorbed by modeling and drawing activities. As the BIM process progress to LOD 400, the overall effort is lower than in the LOD 300 phase; the BIM process absorbed more working drawing effort which declines toward the end. However, project management was more intense at this stage up to the end working drawing production. This is because of the amount of effort needed to coordinate several subcontractors' models. The findings show that the amount of technical effort diminishes while management and coordination effort increased toward the end.

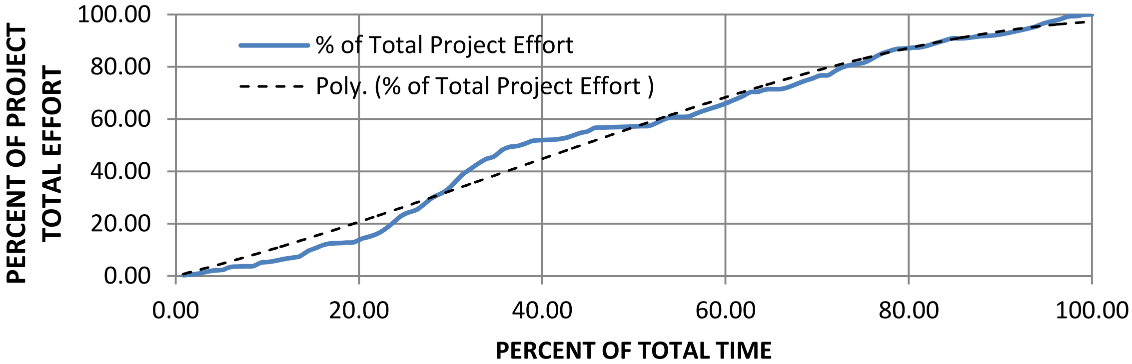

Figure 2. Cumulative effort distribution for Project 'A'.

Effort Distribution Visualization for Working Drawings

Figures 3 and 4 show the effort distribution visualization, and cumulative effort distribution for 'Working Drawing' activities fitted with a polynomial trend lines. Working drawing activities absorbed lower effort at the start which quickly increased and then diminished toward the end. A striking observation in Figure 5 is that 100% of working drawings effort was absorbed by 20% of the BIM process i.e. between 72% to 92% time. The analysis presented in the case study can be applied to other project activities and task. They can be compared and analyzed to give further insight. They have been excluded in this paper because of space limitations.

CONCLUSION

We have described and show how effort distribution can be used to assess the performance of BIM process. The contribution of this paper is that it uses empirical

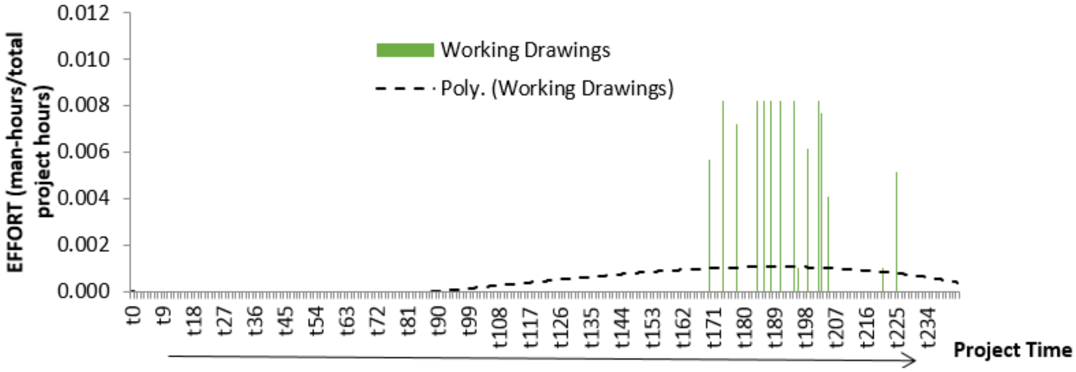

Figure 3. Effort distribution visualization for 'Working Drawing'.

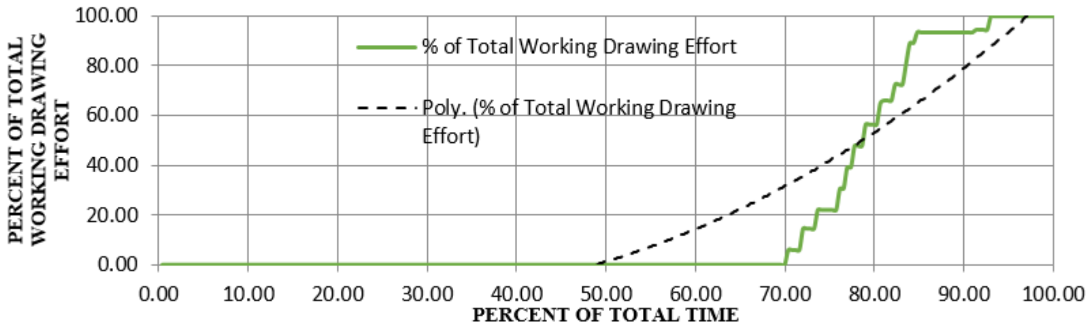

Figure 4. Cumulative effort distribution for 'Working Drawing'.

data to explain how effort distribution can be analyzed to assess BIM project. Effort distribution patterns for a real world BIM project has been presented and described. Striking features were identified. Some context information was used to verify the findings. In the case study project, more effort was expended at the early stage. This resulted in around 30% time savings. Effort distribution analysis can be used in a number of ways: It can be used to identify inefficiencies in the BIM process and to explore strategies for improving productivity by making BIM process more efficient. The visualizations can be used as a tool for post project evaluation. Distribution of effort can reflect BIM management decisions taken during BIM implementation as well as the management styles and organizational attitude to BIM process. Visualizing effort distribution at any stage of a project could indicate future problems e.g. potential risks of changes in design, or likelihood of design errors, rework or clashes. On the basis of the findings, effort can be redistributed and reprioritized in order to correct the undesirable trends and to help avoid problems downstream. It can alert organizations about corrective and preventive actions needed. It can be used to compare the performance of different BIM-based projects and with non-BIM. This is relevant because there is not yet a single best practice BIM adoption strategy. Effort distribution study can provide a guideline that BIM management team can use for developing an appropriate project schedule, deadlines and staffing levels across the project life cycle. Based on the staffing level requirement, organization's cash flow requirements can be determined and can serve as a useful basis for negotiating fee structure with the client. It can inform staff recruitment and staff training. Project managers understanding of effort distribution can help project managers identify critical interfaces between disciplines. Effort distribution can also provide insight into project dynamics from a resource allocation perspective. The dynamics reflects how parties interact, communicate, and how the different aspects of the project integrates to produce the project outcome. Project managers or organizations can identify where efforts were utilized or track where efforts are being utilized and how. Upon project completion, the analysis can support organizational learning for process improvement.

The ongoing research will investigate in-depth the hypothesis that the ratio of the effort spent on project activities occurring in the early project stage would impact on the project outcomes i.e cost, time and number of defects etc; as well as the relationship between effort distribution and organizational outcomes, organizational characteristics and project characteristics. The outcome can help companies and projects teams proactively manage BIM process. It can be hypothesized that the ratio of the effort spent on project activities occurring at the early project stage would impact on number of defects, number of clashes in design, number of RFI, number of changes, and thereby project cost, time and quality performance

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