A PERFORMANCE STUDY OF PROJECT SUSTAINABILITY: REDUCING CONSTRUCTION WASTE THROUGH BIM

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ABSTRACT

The use of Building Information Modeling (BIM) technologies and processes is rapidly becoming a normal happening in the construction industry today. Research studies have been documenting BIM's impact on project cost as well as other construction performance metrics. This paper specifically showcases the impact of BIM on an environmental sustainability metric for construction projects: construction waste. Construction waste accounts for a substantial portion of landfills around the world; therefore, this metric should be used as one of the key performance metrics when discussing the sustainability of any construction project. The methodology for this study first consisted of collecting data from construction projects that have used BIM with various intensities, then the construction waste metrics were analyzed against the level of BIM intensity on the projects. The results suggest a correlation between BIM use and levels of construction waste, but the R^2 values were relatively low due to the limited sample size. Therefore, the findings of the paper provide a stepping stone and a call for more research to investigate the sustainability benefits that BIM can offer the construction industry.

Keywords: building information modeling, construction waste, sustainability

1. INTRODUCTION

A building information model is commonly defined as a model that characterizes the geometry, spatial relationships, geographic information, quantities, properties of building elements, cost estimates, material inventories, project schedules, and relevant data needed to support the design, procurement, fabrication, and construction activities required to realize a built facility (Eastman et al. 2008; Azhar 2011). The use of Building Information Modeling (BIM) tools and processes is quickly increasing in the construction industry, and several studies have shown that using BIM on construction projects can help improve several performance metrics, including project cost, schedule, and quality (Eastman et al. 2008; McGraw-Hill 2009). However, little has been written regarding how BIM affects the sustainability performance metrics of projects, and no studies were found to specifically address how BIM impacts the construction material waste resulting from construction projects.

2. LITERATURE REVIEW

First, the paper presents a summary of the literature review conducted to investigate the metrics that have been previously studied and to serve as a baseline for this study. Azhar et al. (2008) illustrated the cost and communication benefits of BIM through two case studies provided by the Holder Construction Company. In one case study, the building information model detected over 2000 clashes and errors prior to bidding and construction. In the other case study, the building information model created for the architectural and structural systems, as well as the mechanical, electrical and plumbing (MEP) systems of the proposed building, allowed the project team to identify and resolve 590 systems conflicts, saving an estimated $200,000 and avoiding months of potential delays.

Zuppa et al. (2009) surveyed 202 architecture, engineering and construction professionals to gauge their perceptions regarding the impact of BIM. The majority of respondents answered that the use of BIM can improve productivity (75.2%), schedule (83.2%), cost (84.2%), and quality (88.1%).

Giel and Issa (2009) discussed case studies to determine the return on investment (ROI) associated with BIM. Two comparative case studies involving pairs of similar projects were conducted; the ROI for the first case study was 16.2% and the ROI for the second case study was 299.9%. Azhar (2011) collected cost data from 10 projects to perform a BIM ROI analysis. The ROI varied from 140% to 39,900%, with an average value of 1,633% for all projects and 634% for projects without a planning or value analysis phase.

Becerik-Gerber and Rice (2010) surveyed 424 professionals and identified that the top three BIM functions used on construction projects are visualization, clash detection, and creation of as-built models. Around 41% of the respondents realized an increase in overall project profitability and 58% found that overall project duration was reduced. Succar (2010) discussed five new metrics that can help assess BIM performance on a project: BIM capability stages, BIM maturity levels, BIM competency sets, BIM organizational scales, and BIM granularity levels. His five components have a great potential to standardize, assess and improve BIM performance.

More recently, Barlish and Sullivan (2012) performed case studies to determine BIM benefits with respect to project schedule, change orders, and RFIs. The BIM SmartMarket Report (McGraw Hill 2012) conducted a survey of 582 industry professionals and gauged BIM's benefits of collaboration, spatial coordination, MEP prefabrication, constructability reviews, and visualizations that more effectively engage a wide variety of stakeholders. Hanna et al. (2012) identified the state of practice of BIM in the MEP construction industries, benchmarking their experiences with BIM, their cost of using BIM, and the benefits they derived from BIM, which included reducing field conflicts and improving coordination. Kunz and Fischer (2012) listed six project-level outcomes that could be affected by the proper use of BIM on a construction project: safety, function, cost, schedule, sustainability, and globalization. This study will specifically tackle one specific aspect of the project sustainability metrics.

Most recently, Bynum et al. (2013) investigated the perceptions toward the use of BIM for sustainable design and construction. Their results indicated that although the majority of the respondents believed that sustainable design and construction practices were of importance within their company, most still believed that sustainability was not a primary application of BIM and that project coordination and visualization were instead more important.

3. PROBLEM STATEMENT

As shown by the literature review, several authors have evaluated BIM performance related to key metrics, such as project cost and schedule. However, there was little quantitative evidence of how BIM can affect the sustainability of a project. Instead, several industry members do not perceive BIM applications to project sustainability as holding primary importance. This paper intends to shed some light on how BIM can potentially offer benefits to various sustainability aspects of a project, some of which are often discounted, such as construction waste.

Construction waste accounts for a substantial portion of landfills around the world. For example, in Canada, 35% of the space in landfills is taken up with construction waste (Kofoworola and Gheewala 2009). The construction waste metric should be used as one of the key performance metrics when discussing the sustainability of any construction project. In fact, the Leadership in Energy and Environmental Design (LEED) rating system rewards high recycling rates of construction waste (USGBC 2013). Books written on using BIM to catalyze sustainable design also discuss construction waste (e.g. Krygiel and Nies 2012), but there is no proof of BIM actually reducing construction waste.

The main premise of this paper is that BIM can potentially reduce the amount of construction waste generated on a project. BIM allows for the virtual planning and construction of a project before it is physically built, which can directly and indirectly affect construction waste. One example is the use of BIM to increase prefabrication and therefore reduce construction materials on the site; another example is using BIM to provide insights into construction material flows on the project and therefore allowing for better planning of materials and more potential for recycling. The hypothesis tested in this paper is whether an increase in BIM use will decrease construction waste resulting from the project.

4. RESEARCH APPROACH

The research approach of this study consisted of identifying key variables, collecting and analyzing project data, in order to finally discuss the results. The key input variables were identified from the literature review and were grouped in four different areas, as shown on the right side of Table 1 (Survey Level). The four areas were further grouped into two main sets of variables: “potential for BIM effectiveness” and “extent of BIM use.”

Table 1: BIM Data Characteristics

<table>
<tr><th>Analysis Level</th><th>Intermediate Level 1</th><th>Intermediate Level 2</th><th>Survey Level</th></tr>
<tr><td rowspan="4">BIM Score</td><td rowspan="2">Potential for BIM Effec-tiveness
(A)</td><td>BIM Experi-ence</td><td>Owners, Architects, Engineers,
General Contractor, Subcontractors</td></tr>
<tr><td>BIM Infra-structure</td><td>BIM Protocol Manual,
Right of Reliance,
Joint Servers</td></tr>
<tr><td rowspan="2">Extent of BIM Use
(B)</td><td>BIM Functions</td><td>Visualization,
Space Validation,
Site Logistics,
Environmental Analysis,
Early Design Coordination,
MEP Coordination,
Design Collaboration,
Clash Detection,
Submittals,
Estimating,
4D Scheduling,
Digital Fabrication
Construction Simulation,
Project Turnover,
Facilities Management,
Rule/Code Checking</td></tr>
<tr><td>BIM Systems</td><td>Foundation, Structure, Interior Finishes, Exterior Enclosure, Roofing, Mech. Syst., Elec. Syst., Site, Process Equipment, Con-veying Syst. and Specialties.</td></tr>
</table>

The potential for BIM effectiveness (A) includes the BIM experience of stakeholders and the BIM infrastructure for the project. The experience of the different stakeholders with BIM is gauged on a scale of [0,1,3,9] and then averaged across all stakeholders to get one score for BIM experience. The BIM infrastructure questions take binary answers and include the existence of a BIM protocol manual, the contractual right of reliance on 3D models, and the use of joint servers; these individual scores are all added together. The resulting value is averaged with the score for stakeholders’ BIM experience to result in the potential for BIM effectiveness; i.e. the more experienced the team is with BIM and has the infrastructure for it, the more the use of BIM is likely to result in better performance.

The extent of BIM use (B) includes the amount of modeled systems and BIM functions that were exploited on the project. The building systems that were modeled using BIM are determined individually on a scale of [0,1,3,9] and then averaged across all systems. The functions for which BIM was used also are rated on a scale of [0,1,3,9] and then averaged to obtain a variable that reflects the extent of BIM functions in the project. These two variables are multiplied to gauge the extent to which BIM was used on the project.

Subsequently, intermediate variables (A) and (B) are multiplied to compute a single variable that represents the BIM score of a given project, as shown in Figure 1. This method is similar to methods used to account for risk items, by multiplying their probability and impact scores. The final BIM scores are then normalized to the range [0,1].

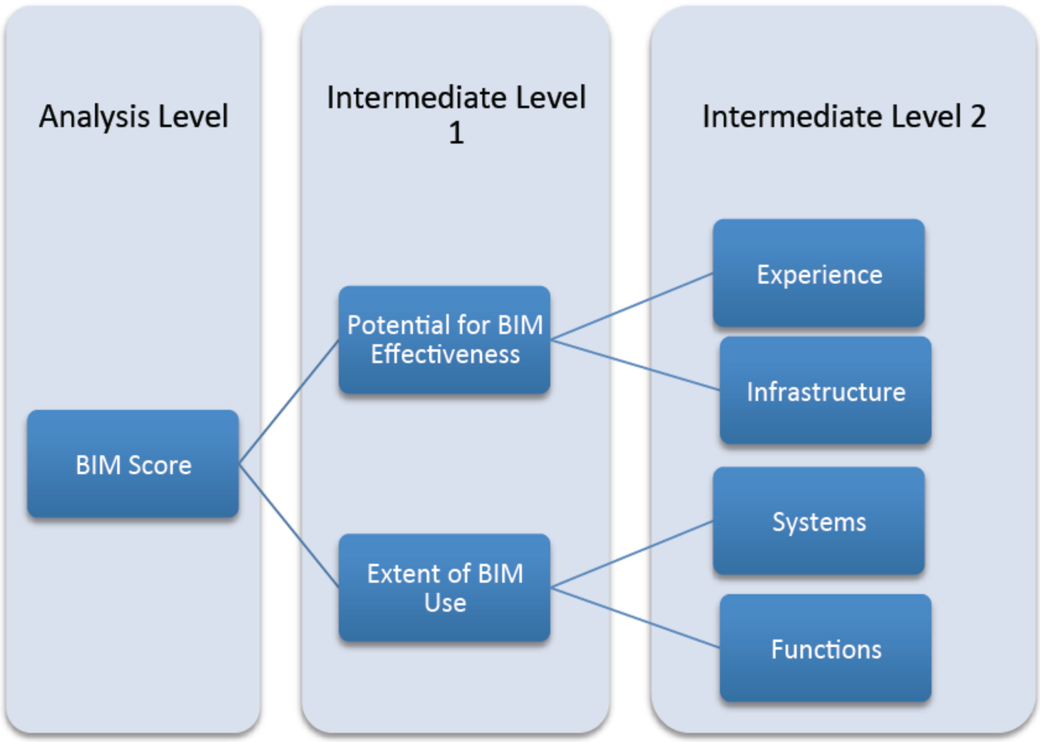

Figure 1: Grouping the BIM Variables

Data was collected for all the inputs identified earlier, as well as two outputs: (1) the total weight of construction waste produced, in tons, normalized by the total dollar value of construction, and (2) the percentage of waste recycled on the project. Data was collected from 28 projects completed in the U.S., which used various levels of BIM. Their BIM scores were calculated to reflect the different levels of BIM use, and then the construction waste performance metrics were plotted against the BIM scores.

5. RESULTS

The minimum construction waste value was 1.5 tons of waste per million dollars of construction, and the maximum value was around 402 tons of waste per million dollars of construction. The average value was 110 tons and the standard deviation was 109 tons. When plotted against the projects' BIM scores, Figure 2 shows an interesting decreasing trend of construction waste for projects with high BIM scores. The R^2 value is fairly low, but this uncovered trend is nevertheless noteworthy and warrants further analysis.

One potential explanation for this trend would be that BIM allows for an increase in prefabrication, resulting in less construction waste. Another potential explanation would be that the use of BIM for clash detection early on in the project could be resulting in a decreased amount of rework, and therefore decreasing construction waste resulting from the project. Additionally, higher levels of BIM use are providing a deeper understanding of projects, including material flows for these projects, which could lead to more recycling to divert waste from landfills. These explanations remain to be tested.

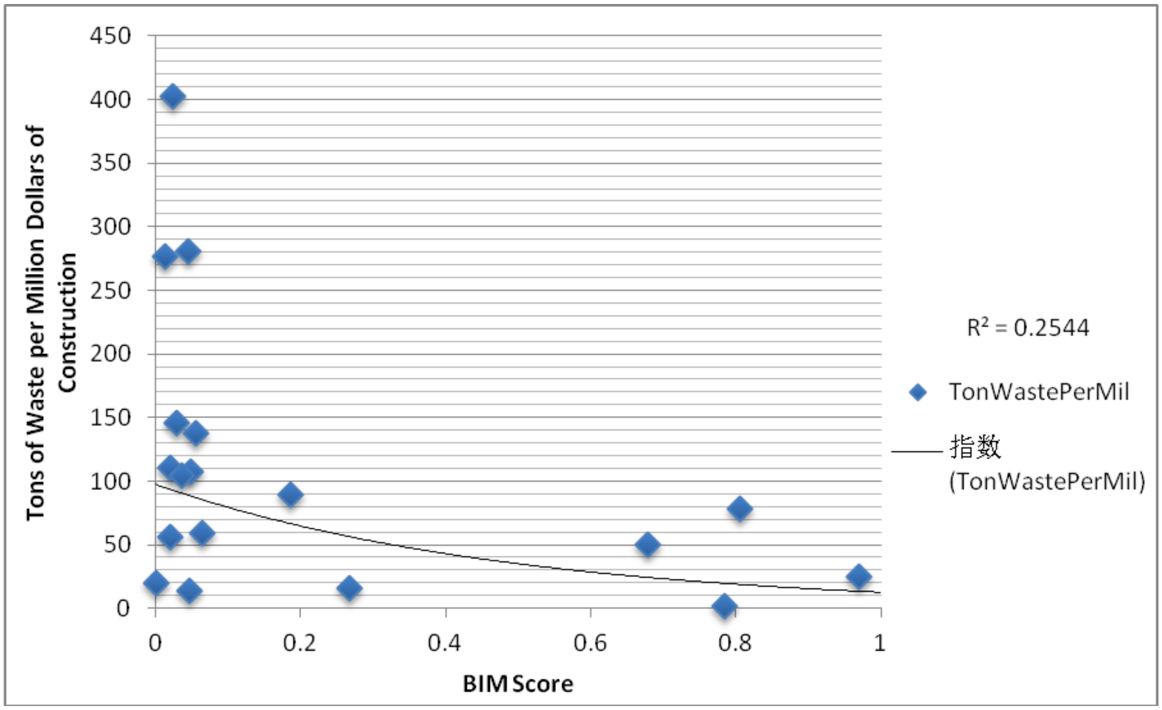

Figure 2: Tons of Construction Waste vs. Level of BIM Use

The second metric that was investigated is the recycling rate of construction waste. The minimum construction waste recycling rate value recorded in the dataset was zero percent, while the maximum recycling rate recorded was 98 percent. The average value was 72 percent and the standard deviation was 30 percent. When plotted against the projects' BIM scores, Figure 3 shows a trend of increasing waste recycling rates for projects that have higher BIM scores. Again, the R^2 value is low in this case.

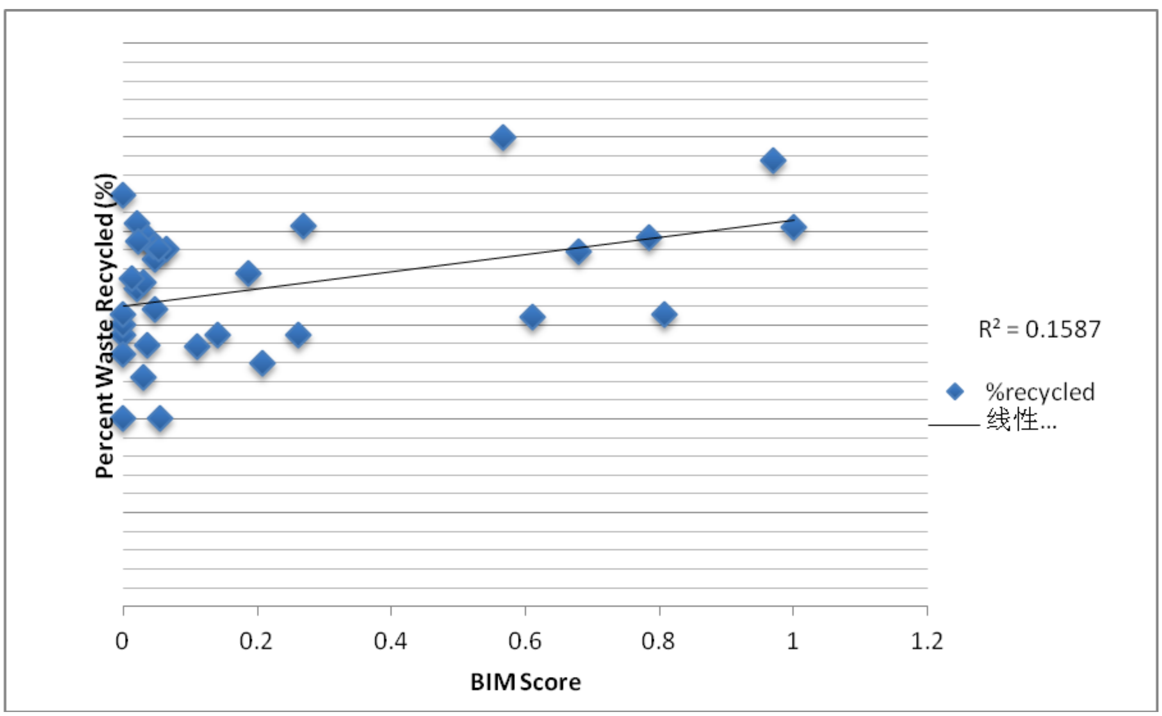

Figure 3: Percent of Construction Waste Recycled vs. Level of BIM Use

A potential explanation for higher recycling rates would be that BIM allows for a better understanding of the project material outputs, resulting in better planning for recycling. However, one could also argue that stakeholders that use BIM heavily are likely to be more progressive organizations that care about sustainability and therefore are more likely to have recycling initiatives in place. The causality cannot be tested in this preliminary analysis and would likely produce an interesting topic of future research.

6. CONCLUSION

This study is a step in the direction of understanding the potential sustainability benefits that BIM offers the construction industry. The statistical significance of the preliminary results presented is not decisive; however, some very interesting trends were uncovered and grant further research and discussion. Building on this paper, future work can include reviewing a greater sample of projects and a wider array of statistical methods to analyze whether there is a definitive correlation between the use of BIM and several project sustainability metrics, including construction waste.

The construction literature has already shown financial benefits for construction firms that use BIM on their projects. Conversely, this study contributes to the body of knowledge by providing insights into another metric that should be of interest to the industry as a whole, in order to address the large problem of construction waste and enhance the sustainability of the construction industry.

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