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Assessing the Performance of the BIM Implementation Process within a Small Specialty Contracting Enterprise

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Abstract

The current shift to Building Information Modeling (BIM) enabled project delivery in the construction industry is promising important benefits. For small and micro businesses, which represent 99.0% of the employers in the Canadian construction industry, adopting these trends could significantly impact their bottom line. However, this often represents considerable cost and risk. Assessing the performance of BIM implementation therefore becomes an important part of the process, namely in ensuring that it is on track and progressing as required. This article presents the findings from a case study research project conducted over a two year period within a small mechanical contracting firm. The objective of this research project was to develop an evolutionary approach, supported by specific measures, to assess the performance of the BIM implementation process within a specialty contracting small enterprise. The findings suggest that BIM has had a positive impact over time on predictability for indicators such as total project cost and labor cost. On the other hand, project scope and quality were not shown to be influenced by BIM in the projects studied. The variability uncovered in the findings reinforces the central tenant of BIM as an enabler for collaboration. Indeed, most of the projects studied were performed in a lonely manner and thus the measured impact of BIM on project delivery was limited, even if it was perceived as very beneficial. Lastly, the article highlights the need for a parallel reconfiguration of practice: performance assessment and BIM implementation need to be developed conjointly to serve one another.

Keywords

Performance Assessment, Measurement, Benchmarking, Building Information Modeling, predictability, Small or Medium Enterprise (SME), Construction, Specialty Contractor,
1 Introduction

Building Information Modeling (BIM) enabled project delivery promises significant benefits across the project supply chain and its lifecycle. It also represents considerable risk for organizations due to the many challenges in its adoption and implementation e.g. (Becerik-Gerber and Kensek 2010)). BIM implementation can be defined as an ongoing process through which an organization modifies its practices to suit the emerging capabilities offered by the transition to a parametric, information rich, digital representation of a built asset (NIST 2007). There are many reported benefits to this transition to BIM, however they remain either anecdotal, intangible or based on conjecture. For organizations, Small or Medium Enterprises (SME) in particular, implementing BIM represents significant risk: anecdotal evidence and faith are insufficient as justification (Gao and Fischer 2008). The transition to BIM has reinforced the need for organizations to assess their performance to many ends such as evaluating benefits and impact of BIM, measuring capability and maturity and evaluating return on investment (ROI). Attaining these ends carries its own set of distinct challenges, namely determining a consistent assessment process adapted to the contextual nature of the construction industry (Poirier et al. 2015), isolating specific actions or elements and determining their impact on project performance (Andresen et al. 2000) and correctly identifying project dependencies (Sosa et al. 2007). While past work has looked into defining success measures and determining the value of BIM at either the project level or at the organizational levels, little work has been done to bridge the gap between both levels. Many of these studies are survey based, therefore self-reported, and few have objectively looked into the progression of BIM within an organization over an extended period of time.

This article presents the findings of a 2 year research project with a small mechanical contracting enterprise. The objective was to develop an evolutionary approach, supported by specific measures, to assess the performance of the BIM implementation process within the organization. This was done by measuring the predictability of key performance indicators on 8 different projects that were aggregated at the organizational level through a centralized database. The focus of the research project was purposely put on small (between 5 and 99 employees) and micro (less than 5 employees) businesses who, in 2012, made up 99.0% of the
Canadian construction industry’s workforce (Industry Canada 2014) and accounted for 72.7% of the total share of nominal GDP in the Canadian construction industry (Leung et al. 2012).

The contribution of this article is the systematic approach taken to the assessment of BIM implementation within a specialty contracting SME through the evaluation of variability of key performance indicators across time. While past research has looked into the performance and impact of BIM at the project level or, through surveys, at the organizational or industry levels, this article bridges the gap between these two levels. Our findings suggest that BIM has helped the Organization improve the predictability of certain cost items, namely total project costs and labor costs. The Organization is also becoming better at evaluating the costs associated to BIM implementation at the project level. On the other hand, the quantity and cost of change orders (CO) and the amount of rework were not seen to be impacted by BIM. The key contributions from this article are three fold: it provides empirical support to the notion of BIM as a collaborative undertaking and the importance of providing a conducive project environment to maximize value. Indeed, the use of BIM in the cases reported in this article were mostly executed in a lonely setting, as such, the organization did not benefit from BIM to the extent that has been reported elsewhere. This speaks to the Organization’s lack of influence on decisions made upstream within the project supply chain, namely around the extent and scope of BIM use in a project. It also highlights the parallel courses of the BIM implementation and performance assessment practices: an organization’s performance assessment practices should reflect the reconfiguration of practice introduced by BIM. Finally, the article adds to the growing literature relating the quantified benefits of BIM, which can help inform the adoption and implementation of BIM within the Canadian construction industry.

2 Background

The well-researched fields of performance assessment and benchmarking in the construction industry highlight the imperative need for consistent evaluation of performance in order to compel progress and innovation (Bassioni et al. 2004). With regards to BIM implementation, multiple perspectives on performance assessment have emerged in the literature. These perspectives focus mainly on evaluating the impact of BIM at the project level (Khanzode et al. 2008), assessing the progression of capabilities and maturity (Succar et al. 2013, Taylor and Bernstein 2009) and measuring return on investment (ROI) (Barlish and Sullivan 2012, Giel and...
Issa 2011). The use of key performance indicators (KPI) is seen as the most popular method of measuring performance in the construction industry (Robinson et al. 2002) and therefore, considerable work has gone into identifying and implementing frameworks based on these indicators (Kagioglou et al. 2001). Over the past two decades, many KPIs have been identified ((Chan and Chan 2004, Cox et al. 2003)) which are typically related to one of 7 categories: Cost, Time, Quality, Safety, Scope, Innovation and Sustainability (Rankin et al. 2008). The emergence of BIM performance assessment as a field of study has benefitted from this work, leveraging it to focus on measuring the impact of BIM. There is, however, a vast discrepancy within the KPIs being tracked to do so (Neelamkavil and Ahamed 2012). In this regard, BIM shows potential to influence mostly quality control, on-time completion, reducing change orders (COs) and requests for information (RFI) as well as improving labor productivity (Barlish and Sullivan 2012, Khanzode et al. 2008, Suermann 2009). Table 1 summarizes many of the measures that have been developed in the construction industry and been subsequently used to assess the performance of BIM.

| Table 1 - KPIs and metrics from the literature |
| [INSERT HERE] |

Some studies have used cost growth as a measure of performance, namely Kelly and Ilozor (2013) who find that BIM has a negative impact on cost growth on the projects studied, which is contrary to general themes in the literature. This notion of predictability holds much potential in serving as a true indicator of performance (Forbes and Ahmed 2011, Koskela 1992) and was one of the measures developed by (Rankin et al. 2008). Indeed, better predictability indicates lower risk and while the seven areas of measurement (Cost, Time, Quality, Safety, Scope, Innovation and Sustainability) offer quantifiable and finite indicators, the true measure of performance lies in their predictability over time. While, the literature pertaining to BIM performance assessment has mainly focused on individual projects at specific points in time, some work has supported an organizational perspective of BIM performance assessment, namely (Coates et al. 2010) who argue that “KPIs should be measures of risk to annual goals and strategic objectives” (Coates et al. 2010, p.6).
From this perspective, some work has looked at evaluating ROI as a measure of expenditure (risk) in relation to quantifiable benefits (achieving strategic goals and objectives). It leverages the KPIs that have been identified elsewhere to justify the cost of BIM within an organization. The literature on ROI differs from that on impact assessment by identifying the various costs associated to BIM such as hardware, software, training, recruitment and contingencies (Olatunji 2011). Some take a simpler approach to the ROI calculation where expenditures are uniquely attributed to cost of modeling on a project and return is defined by elements such as avoidance of issues in the field through early resolution. For instance, Giel and Issa (2011) provide a model for estimating BIM ROI, calculating an ROI of BIM ranging from 16% to 1,645% on the projects they studied. This method, however, remains highly hypothetical since it assumes that the issues avoided through the model would not have been avoided using traditional coordination methods. Moreover, frameworks have been developed to further systematize the ROI evaluation process both from the purely quantitative perspective, providing investment and return metrics, comparing BIM to non-BIM projects (Barlish and Sullivan 2012) and balancing both the quantitative and the qualitative perspectives (Love et al. 2013). To date, the operationalization of these frameworks provides insight into the beneficial impact of BIM at the project level, however, these findings remain inconclusive due to the underdeveloped use of BIM in many of the projects studied (Barlish and Sullivan 2012). There is great interest in developing this field.

The third area of enquiry is that of capability and maturity assessment. Several frameworks and tools to evaluate the BIM capabilities and maturity levels of an organization have been developed over the past years such as, among others, the BIM Maturity Index (BIMMI) (Succar 2010), the Computer Integrated Construction research program’s organizational maturity assessment matrix (CIC 2013), the National Institute of Building Science’s Interactive BIM Capability Maturity Model (NIST, 2007) and the VDC/BIM Scorecard (CIFE 2013). Commercial tools have also been developed such as BIM quickscan (Sebastian and van Berlo 2010) and bimScore (Kam et al. 2012). The focus is mainly around the evolutionary nature of BIM within the organization (e.g.Taylor and Bernstein 2009). These models are, however, often based on conjecture and require an objective introspection on the part of the organization performing the assessment.
Some authors have tried to overcome this subjective approach to assessment, such as Mom and Hsieh (2012) who propose a BIM Performance Assessment Framework (BIMPA). This BIMPA is operationalized “at the corporate level, which attempts to identify, control, predict, measure, and improve the critical factors that affect construction business performance” (p.2). The issue lies in that the framework intimates a “clean” and linear BIM implementation process at the organizational level while not factoring in the importance and the influence of project level BIM implementation nor the context of the implementation. (Du et al. 2014) have developed the BIM Cloud Score to benchmark the modeling process. The authors hope that through this approach organizations can benchmark their “BIM performance”. The BIM Cloud Score seeks to measure the outcome of the modeling process, but it doesn’t look into the project delivery and the various inputs that guide the modeling process; the metrics developed also lack grounding.

In essence, there lacks a way to systematically assess the evolutionary nature of the BIM implementation process within an organization. Indeed, many of the models or frameworks that set out to assess the performance of BIM, either its impact, its return or its evolution, disregard the interactions between the project, the organizational, the institutional and the industry contexts, which are highly interrelated and influence the BIM implementation process (Poirier et al., 2015). Some of the assessment methods that are being proposed also tend to ignore existing organizational measurement processes and tools, which is problematic. Indeed, organizations adopting and implementing BIM are confronted with multiple parallel processes: not only do they have to transform their practices around BIM, they have to reconfigure how they evaluate and track their performance in light of this transformation.

3 Research Methodology

A mixed-method, longitudinal case study research approach (Fellows 2008, Yin 2014) was employed to investigate the performance assessment practices for a specialty contracting SME evaluating its BIM implementation process. This was done across multiple projects by developing specific KPIs and metrics that were based on the organization’s current performance assessment capabilities and practices. This research project was part of a larger, multi-pronged research project aimed at studying the adoption and implementation of BIM within SMEs in the Canadian construction industry (Forgues et al. 2014, Poirier et al. 2013). The scope of this particular research project was conducted over a 2 year period. Its objectives were to (1)
investigate the current performance assessment practices of the organization and (2) to develop an approach, supported by specific measures, to assess the performance of the BIM implementation process within the organization from an evolutionary perspective. The research team was working with the hypothesis that, over time, the implementation of BIM would improve predictability of project scope (less RFIs and Change Orders), of project budget (actual vs. estimated cost), of project schedule (actual vs. estimated duration), of project quality (less rework) and of labor productivity within the organization. In parallel, the cost of BIM at the project level would either be constant or diminish slightly as the organization increased its capabilities in the field of modeling and prefabrication.

To test this hypothesis, eight projects were targeted within the organization for an in-depth analysis: six where BIM was used in a significant manner and two projects which did not involve the use of BIM to serve as baseline comparison cases. Table 2 and Table 3 present the eight projects that were analyzed, four DES projects and four building mechanical projects. The projects are presented in a chronological order. Qualitative data was collected through semi-structured interviews and direct observation. The interviews lasted between 30 and 90 minutes. The personnel interviewed within the Organization were: the president-general manager (who also acts as senior estimator), the construction manager, three project managers, the BIM manager and the principal BIM coordinator. This personnel was involved in all eight projects in one form or another. Cases 01-A, 02-A and 02-B were retrospective, whereas the remaining cases were on-going over the course of the research project. Through direct observation, we identified the estimating and project management practices, notably to determine how the organization estimated, scheduled and managed their projects. We also identified the organization’s performance assessment practices, including the existing infrastructure used to collect and aggregate the data, the measures being tracked, the data collection mechanisms and the data analysis methods.

The quantitative data that were collected for these projects were: Request for Information (RFI) and Change Order (CO) logs, budgets and cost reports, schedules, plans and specifications as well as digital models and employee timesheets for all eight cases. These artifacts were evaluated to identify the current KPIs and metrics being tracked as well as to determine the current status of data available for analysis. The research team reviewed the available data
through the organization’s project management software as well as the level of detail to which it could be extracted for each of these projects.

Table 2 – Description of Selected District Energy Station Projects

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Table 3 – Description of Selected Building Mechanical Projects

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Figure 1 illustrates the systematic and evolutionary approach to benchmarking and performance assessment that was developed and formalized from the direct observation in the early stages of the research process. It bridges the gap between the project level and organizational level by identifying processes belonging to each level and where they intersect. It is evolutionary in that it intimates an iterative approach to the assessment process by continually reassessing the performance assessment strategy as capabilities are developed within an organization, which will in turn modify the scope of the performance assessment process by introducing new measures or data collection points.

Figure 1 - Benchmarking and performance assessment approach

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4 The Organizational context

The Organization we studied was founded in 2004 and operates in the Vancouver, British-Colombia area. It has 67 employees and is deployed along a project-based organizational structure across two divisions: 24 office based employees (project managers, coordinators, estimators as well as administrative staff) who form the project management team and 43 site
based employees (superintendents, foremen, journeymen). Since 2004, they have completed over 50 projects ranging from $100k to $14M in contract value. The Organization delivers projects concurrently across two project streams. Project stream 01 involves the delivery of District Energy (DES) projects including fabrication and installation of Energy Transfer Stations (ETS). Project stream 02 involves the delivery of traditional building mechanical systems including HVAC, fire protection, plumbing, etc. Within both project streams, the organization will typically sub-contract all sheet metal and ducting work, fire protection, pipe insulation and refrigeration while plumbing, HVAC piping and equipment installation will be self-performed work. The organization moved forward with the adoption of BIM in 2010. To date, it has completed 11 projects using BIM, mostly in a lonely setting, meaning that they are the only stakeholder using BIM in the design or construction phase. Six of those projects were targeted in this study due to the considerable scope of BIM use in these cases. The organization has been developing its BIM capabilities in the following areas: on-site and off-site prefabrication, laser scanning, pre-planning, trade coordination, visualization, constructability review, and clash detection.

The Organization has consistently spent 0.8% of their yearly sales volume on BIM implementation. These costs represent the cost of: software licenses (40%), hardware (4%), training (2%) and the overhead salaries and burden of employees dedicated to BIM in the organization who aren’t working on billable work (such as developing libraries, standards, etc.) (54%). Consequently, the organization was seeking a way to justify these overhead costs related to BIM adoption, the project costs of BIM and the concurrent development of capabilities (laser scanning, off-site pre-fabrication, etc.). In fact, the need to consistently measure, evaluate and benchmark the organization’s performance as a key to sustaining the BIM adoption and implementation process was highlighted as one of the main challenges faced by SMEs adopting and implementing BIM (Forgues et al. 2014, Poirier et al. 2013), which is consistent with past work in the field of organizational innovation (Rankin and Luther 2006). The main motivation behind initiating this portion of the research project was therefore to assess the performance of the BIM implementation process within the organization. This was stressed by the Organization’s general manager during an interview, which, when asked about justifying the costs associated to BIM responded:
We don’t know yet. We are doing it [the implementation of BIM] on faith so far and this is why questions arise like this costs analysis of the BIM cost versus our labor productivity to see if there is any correlation there. The very first job we did [where we used BIM] we felt we probably would have lost our shirt if we hadn’t of ‘BIM’ed’ it, but that's anecdotal, we don’t have any measurement of that, but that's our gut feeling. So our gut feeling is still telling us that this is a smarter way to build and more efficient way to build. General Manager (16102013)

4.1 Estimating and project management practices

In order to use predictability of costs as one of the indicators, the estimating practices must first be well understood. The organization’s estimating and management practices relies on the way the project is being procured and delivered. Typically the organization will be involved in design-bid-build (DBB), design-build (DB) or construction management (CM) projects and may be involved in a design assist (DA) role.

DBB is seen as the least desirable delivery mode by the organization, according to our interviews. In the case of a DBB, the estimating and tender process is very short (2-3 weeks) and wrought with uncertainties. The evaluation of project cost is largely based on the experience and knowledge of the personnel who are involved in the estimation process. Estimations are based on a set of 2D drawings and specifications provided by a team of consultants, at varying levels of detail. Estimations are compiled on a software platform that includes a third party costing database. The software allows the estimator to input quantities of specific elements and the software will automatically provide a cost unit and a labor unit. Typically, the estimators will work with the organization’s General Manager and Construction Manager to process the documents and outline the project scope. In addition, on certain projects, they might involve key personnel (Project Managers, Foremen, etc.) to impart additional knowledge and refine the bid. The estimating team will generally go over the project documents and attempt to quantify each element and attach a cost to it’s procurement or fabrication, installation, commissioning and servicing/warranty. Attributing a cost factor to elements is based on quantity with several factors linked to each particular element such as difficulty, schedule, labor, and several other extraneous factors such as weather and market conditions which are compounded into the final estimate. Furthermore, it was stated during one interview that additional provisions are
sometimes made depending on the consulting firm that produced the design based on past experience with these consultants. In essence, outside of the actual count and measure of elements as represented on the plans, there is a considerable amount of factors which are taken into account that rely on the experience of the estimating team.

During the tender process, the estimating team and the subcontractors who are pricing out the work will submit RFIs to refine the design intent and get as much information as possible. Clarifications of plans will be produced under the form of addendum by the design consultants. It is at the tender phase that equivalency requests are usually submitted. Estimating in this context is a highly punctual and rigid process with a distinct input (tender documents + RFIs) and a distinct output (bid). Once confirmation is given and the contract is awarded, the team that prepared and submitted the bid will generally review the entire package, involving the Project Manager more closely this time, to comb over the project once more, go into greater detail and ensure that no major elements have been overlooked or errors committed during the tender phase that could impact project delivery. At this time, the project team will be assembled, including project coordinator and field staff. Contracts will be awarded to sub-contractors based on negotiations involving all those that have produced a bid. One interviewee said that it was at this point, during negotiations with sub-contractors, that any errors or omissions that were made during tender would be negotiated and “patched-over”, risk being essentially transferred to the sub-contractors as much as possible. In the DBB delivery mode, BIM will usually be deployed once the contract has been awarded and its scope will be restrained to a specific area where clear value can be obtained, in mechanical rooms for example. DBB does not provide the opportunity for the organization to use BIM during the tender stage due to the short timeframe and the cost of modeling.

In the DB/CM/DA project delivery mode, more work goes into obtaining the contract as there is a longer proposal and qualification phase, however this form or delivery mode allows the organization to develop a relationship with other project stakeholders which is seen as beneficial by the organization. Estimating plays a large part in obtaining a contract, as the contractor must submit a gross maximum price (GMP). The estimation process is an iterative one. As design is being refined, so is the estimate becoming more and more precise. This allows for a tighter control over the budget as well as presents opportunities to optimize certain design decisions. These design decisions can be rapidly priced via the estimating team and informed
decisions can be made as to how to proceed. Estimating in this context is an evolving and iterative process with many inputs and many outputs. However, once the Organization has submitted their GMP, they are responsible for delivering the project within the agreed price, which carries the risks similarly to a DBB delivery mode. Mobilization happens once contracts are awarded and the project has sufficiently been detailed in order to obtain permits and begin construction. Since the project team has been working together for a longer period of time and essentially all stakeholders have a good overall grasp of the project, the project start-up phase was noted as being much smoother than in the DBB mode due to many issues having been resolved during design. In the DB/CM/DA project delivery mode BIM will be deployed as early as possible to help inform design decisions. To date however, BIM has not been used to inform quantity take offs. The Organization is in the process of developing those capabilities.

4.2 Performance assessment practices

The Organization’s performance assessment practices aim to track cost, schedule and quality as KPIs. These KPIs are tracked at the project level and used to evaluate project progress. The Organization has implemented a centralized project management and enterprise resource planning (ERP) software (Timberline®(Sage 2013)), which allowed easy access to and reporting of project measures (for instance total time allotted for a specific cost code). The data made available through this software are: project estimates, cost reports, schedules, request for information (RFI) logs, change order (CO) logs, and employee timesheets. Our observations allowed us to identify that the data collection mechanisms in place at the project level were reliant on the individual efforts of certain key personnel. Data collection was distributed across a limited number of project team members, namely the project manager, the project coordinator, the site superintendent and foreman. The project manager is mainly involved in aggregating and tracking the high-level key performance indicators such as cost and schedule. He maintains the associated elements in the project management software such as billings, work orders and material orders. He also tracks milestones and schedule items. The project coordinator tracks all project related communications – RFIs, COs, SIs, Shop Drawings, etc. – and maintains the associated logs within the project management software. The site superintendent and the foremen are responsible for the collection of data on a daily basis - activity planning and tracking, material tracking, quality assurance, and issue tracking. We also observed that although the organization had established a practice of tracking data and performance at the
project level, this data wasn’t being aggregated at the organizational level to detect trends in the BIM implementation process. In addition, data collection by the site personnel was seen as a challenge due to their multiple responsibilities, namely work execution, planning, tracking and issue resolution. A lot of time was spent on issue resolution, which didn’t allow much time for other activities - BIM could potentially allay this particular issue.

5 Findings

The analysis of the quantitative data provides an empirical view of the performance of the Organization’s BIM implementation process. The quantitative data, collected on the 8 projects indicated in Table 2, were analyzed. Projects 01-A and 02-A are non-BIM projects serving as a basis for comparison with the other BIM projects. The following KPIs were operationalized to assess the performance of the BIM implementation process across time within the organization:

- Project cost predictability
- Project scope predictability
- Productivity indicator predictability
- Project schedule predictability
- Project quality

5.1 Project Cost Predictability

The first measure we assessed was predictability of cost data. The formula used to calculate this was (Rankin et al., 2008):

$$\text{Cost predictability} = \left( \frac{\text{actual cost} - \text{tendered cost}}{\text{actual cost}} \right) \times 100$$  \hspace{1cm} (eq.1)

A null value (0%) is desirable as it indicates complete predictability. A positive value indicates an actual cost that is superior to the tendered cost, i.e. over-budget. A negative value indicates a tendered cost that is superior to the actual cost, i.e. under-budget. The maximum positive value is 100%; there is no negative value limit. While percentage error, or the measure of predictability, is typically an absolute value (Rankin et al. 2008), the use of negative value allows to see where projects are under budget. We performed the analysis of cost predictability for 5 budget items: total cost of work (excluding profit), direct labor, BIM costs (cost of modeling), site supervision and project management (Figure 2). These 5 budget items were selected as they
involve the Organization’s direct/indirect labor, which is seen as an area where BIM can potentially have significant impact (Khanzode et al. 2008)

Figure 2a illustrates positive values for all cost items across the selected DES projects except total project costs and labor costs for project 01-D. Actual costs for the selected items are thus consistently higher than budgeted costs regardless of BIM implementation except for the aforementioned elements. BIM costs are consistently under estimated with project 01-B showing 100% variability, indicating that no costs were carried for BIM at tender. They are tending towards 0% however, which could indicate a better grasp of costs associated to BIM by the Organization as it gains experience with BIM on DES projects. Furthermore, the three projects where BIM was implemented show an improvement in cost predictability for total project costs and labor costs. This can be interpreted as BIM potentially having a positive effect on ensuring better cost predictability on these budget items. Moreover, the Organization is developing an expertise in DES projects, supported by BIM, which could explain the overall trend towards better predictability across time for the cost items discussed. Figure 2b illustrates significant variance for many cost items across the selected Bldg. projects. Site supervision is consistently under budget for projects having deployed BIM. On the other hand, project management is consistently over budget for all projects. Project 02-B shows 100% BIM cost variability, indicating that no costs were carried for BIM at tender, while project 02-C shows -116% BIM cost variability, indicating that BIM costs came significantly under budget. This is due to the fact that the scope of BIM was significantly pulled back during the project and limited to a very small, yet highly complex area. Total project cost predictability for projects 02-C and 02-D as well as site supervision cost predictability for project 02-C are very good. That being said, it is difficult to draw a clear causal link between the use of BIM and cost predictability in the case of building mechanical projects due to the many variables that come into play. However, by maintaining the database, a clear trend could emerge that highlights the impact of BIM over time on this indicator.

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Figure 2 - Cost - Cost predictability

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Figure 3 illustrates the variability between actual and estimated cost of BIM as a percentage of
total labor cost; it is an attempt to establish a clear benchmark relating to the cost of BIM. The
average actual cost of BIM is 6.2% of actual labor costs on DES projects while it is 2.5% on Bldg.
projects. These values are highly dependent on the scope of modeling and the context in which
BIM is deployed, however it gives a sense of scale for the cost of BIM in relation to the cost of
labor. The difference between the tendered and actual costs tend towards 0%, with projects 01-
D, 02-C and 02-D showing a difference of 1.5% or less. It can be interpreted that as the
Organization gains experience with deploying BIM in their projects, they are rapidly becoming
better at evaluating the cost of BIM. As the Organization progresses in its BIM implementation
process, the expectation would be that for the DES projects, due to repetition and the similar
nature of project settings, the percentage of BIM costs compared to labor costs would decrease
over time, i.e. BIM would become less expensive. For the building mechanical projects, this
decrease could be expected between similar projects and as the Organization gains experience
in the modeling and coordination of mechanical models. However, this trend may be less clear
due to the multitude of factors influencing building mechanical projects.

5.2 Project scope predictability

Figure 2 suggests relatively low cost predictability for certain budget items across both project
streams. This could suggest many things. For one, it could suggest that a lot of changes were
issued during the construction phase. This is confirmed to a certain extent by Figure 4, which
indicates the total cost of change order (CO) as a percentage of total cost of work. Furthermore,
contrary to past research, Figure 4 suggests no clear impact of BIM on the number of COs in
either DES project or building mechanical projects. This could be caused in part by the lonely
setting in which BIM was implemented and the limited influence the Organization has over
project delivery in the supply chain – i.e. being “the last to BIM” doesn’t allow the Organization
to influence upstream decision making and thus impact the quantity and scope of COs.
5.3 Productivity indicator Predictability

One of the measures of productivity is that of input (time, cost, etc.) per unit of output produced (Durdyev and Mbachu 2011):

\[
\text{productivity} = \frac{\text{input}}{\text{output}}
\]  

(eq.2)

In this case, cost per unit produced, both for labor and for BIM, were analyzed as an indicator of productivity. For the DES projects the unit used was dollar ($) per ETS. For the building mechanical projects, the unit used was dollar ($) per square foot of total project area. Figure 5 illustrates the variations between tendered labor costs and actual labor costs per unit for all eight projects (also illustrated in Figure 2). While the labor cost per unit is difficult to compare between projects, due to the variable contexts, its predictability across all projects nevertheless constitutes a considerable risk for the organization. For the DES projects, predictability trends towards a null value, whereas this is not the case for building mechanical projects. Furthermore, a major difference is noted between non-BIM and BIM projects for the DES projects, which, along with increasing overall expertise in this particular area, potentially indicates a positive impact of BIM on the predictability of labor productivity. The data are inconclusive for the building mechanical projects. Furthermore, the use of gross floor area as a productivity unit is questionable and is addressed in (Poirier et al. Forthcoming)

Figure 6 illustrates productivity rate – units performed per unit of time (output/input). This is different from cost per unit performed (Figure 5) since the measure doesn’t include the pay grades and burden of the employees. It is an indication of direct time required to perform a task. For the DES projects, the units performed represent the quantity of ETS’ (or fraction
thereof) performed per hour. The secondary axis represents the number of hours it takes to complete one ETS. For building mechanical projects the units performed represent project area performed per hour. The predictability of productivity rate in both streams is highly variable across projects, with projects 01-B, 02-A and 02-B having a lower actual productivity rate than estimated, while actual productivity rates for projects 01-A, 01-C, 01-D, 02-C and 02-D are superior to estimated productivity rates. On the DES projects where BIM was used, a significant increase in field productivity rate is noted for projects 01-C and 01-D. The use of BIM driven, off-site prefabrication for these projects could potentially explain this increased productivity. The baseline project 01-A also shows better actual productivity. As such, the comparison to non-BIM project offers no ground to state that BIM was beneficial in this case. For the building mechanical projects, both projects 02-C and 02-D show better actual productivity, which can be attributed also to BIM driven, off-site prefabrication, especially for the mechanical rooms. Again project context is crucial in this case, as the organization’s productivity is greatly reliant on the overall management of the project by the general contractor (i.e. crowding, sequencing, etc.) as well as many other project specific factors. This particular measure of the impact of BIM on labor productivity is further investigated in Poirier et al (forthcoming). That being said, as the Organization builds its database, trends could emerge per project type, procurement mode and level or BIM implementation.

Figure 6 - Productivity - unit per time

(INsert here)

(INsert here)
Figure 7 illustrates the variations between tendered BIM costs and actual BIM costs per unit for all eight projects (also illustrated in Figure 2). Except for project 02-C, all other BIM projects studied had an actual cost of BIM that was superior to the tendered cost. This speaks to BIM costs being underestimated. The average actual cost of BIM per unit for the DES projects is approximately $3,500.00 per ETS while it is $0.11 per sq.ft of total project area. This indicator serves as a baseline to compare future projects against. Indeed, as the Organization gains experience, it is expected that this average cost per unit should remain stable or decrease. Again, this is highly dependent on project context and scope of modeling, however it can serve as a way to assess the efficiency of BIM use and progress of implementation.

---

**Figure 7 - Productivity - BIM cost per unit**

(INsert Here)

---

### 5.4 Project Schedule Predictability

Figure 8 illustrates the predictability of labor duration across the projects studied. The formula used to calculate this was (Rankin et al., 2008):

\[
\text{Schedule predictability} = \frac{\text{actual duration} - \text{tendered duration}}{\text{actual duration}} \times 100 \quad \text{(eq.4)}
\]

As per cost predictability, a positive value indicates an actual duration that is superior to the tendered duration and vice-versa. The wide variation across all projects and the misalignment between schedule predictability and cost predictability could be due to the estimating process utilized by the Organization (cf. section 4.1), whereby labor units are associated with quantities, thus duration is a factored by-product of estimated quantities. It could also be due to changes issued during the construction project. It is important to note that this particular measure is not representative of overall schedule predictability. The durations shown in Figure 8 are direct durations taken from each project’s timesheets and estimates provided by the organization, not the scheduled durations established by the project management team. While they are typically correlated, i.e. the estimated labor units inform the duration of an activity, the sequencing of work is left to project managers who can optimize the schedule and adapt it to the General
Contractors master schedule. In this case, BIM is not shown to have an impact on scheduled duration across the projects studied.

Figure 8 - Schedule - Predictability of Labor duration

(INSERT HERE)

5.5 Project Quality

We analyzed the cost of rework and deficiency repair as an indicator of project quality. For the building mechanical projects, either data was missing or the actual rework performed very limited, totaling less than 0.001% of total project costs. For the DES projects no clear trend was discernable regarding a decrease in rework for projects where BIM was implemented.

6 Discussion

6.1 Analysis of the findings

Our observations and analysis confirm the considerable challenges associated with assessing the performance of BIM implementation at both the organizational and project level; dissociating the use and impact of BIM from the project context is a significant, if not impossible, challenge. Thus, for the KPIs that were targeted and their respective metrics, it is challenging to draw clear conclusions concerning the performance of BIM within the projects studied and its evolution within the Organization. By formulating and testing the hypothesis that the implementation of BIM within the Organization would improve predictability of project costs, schedule, scope, productivity and quality of projects, we were attempting to identify trends in the behavior of the metrics with regards to BIM use and evolution across time. Our findings suggest that indicators such as predictability of total project costs and labor costs for DES projects (Figure 2a) as well as cost of BIM as a percentage of total cost of labor (Figure 3) show an improvement across time on projects where BIM was implemented by the Organization. However, for other indicators, such as cost conformance for building mechanical projects (2b) or schedule conformance (Figure 8) there is no clear trend marking a positive evolution of BIM within the Organization. In addition, indicators, such as cost of BIM as a percentage of total cost of labor (Figure 3) and BIM
costs per unit (Figure 7) have a lot of potential in serving as a benchmark within the Organization. In accordance with the main hypothesis that was formulated, it could be put forth that the cost of BIM for the Organization will remain stable or decrease over time as they gain experience. The same can be said for labor productivity (Figure 5 and Figure 6) which should tend to improve as the Organization moves towards pre-fabrication. This was confirmed to a certain extent in Figure 6.

These measures are, however, extremely reliant on project context, which includes project type and scope, delivery mode, position of the organization within the supply chain as well as the level and scope of BIM implementation. This is supported by the apparent lack of influence of BIM on the predictability of project scope, namely the quantity and cost impact of change orders (Figure 4). This particular metric has been reported elsewhere as an indicator of the positive impact of BIM on project outcome (e.g. Barlish and Sullivan, 2012, Khanzode et al. 2008). Therefore, this apparent disconnect between the findings of this project and those presented elsewhere reinforces the notion of BIM as a collaborative undertaking, where true value is obtained when BIM is implemented across the project supply chain (NIBS, 2007). In this light, the approach and measures presented here can provide targets for the organization to reach and help inform the implementation process.

6.2 Transforming practice

While we observed and analyzed the performance of BIM implementation within the Organization, we also observed the shift in practice that was required to develop the benchmarking and performance measurement capabilities. Indeed, we observed many shortcomings with the Organization’s current performance assessment capabilities. For example, performing project post-mortems as well as extracting project data to maintain a database to benchmark and track project performance was not a common practice. This was explained as being a symptom of the fast paced and unpredictable nature of the construction industry, which requires that project personnel be involved on many projects at once and jump from one project to the next with little time to perform a post-mortem analysis of completed projects. This step is crucial in the benchmarking and performance assessment process to bridge the gap between the project level data and its aggregation at the organizational level (figure 1). The research project attempted to facilitate this aggregation by identifying which data points should be aggregated to populate the database.
Furthermore, if predictability is to become a longitudinal measure of performance at the organizational level, there is a need for more precision in establishing budgets and schedules as well as determining what an acceptable variance (delta) is. Indeed, it was confirmed during discussions with estimators that labor units are often adjusted during the estimating process and that it is heavily reliant on heuristic methods. This is explained in part by the short time frame estimators have to estimate a project in a DBB setting. The Organization should look into leveraging BIM to assist in establishing the project budgets and tenders.

The benchmarking process requires a lot of data, captured over a long period of time, in order to establish clear trends in the performance assessment that can be filtered according to project type, procurement and delivery mode, level of BIM use, etc. It also requires a lot of time and effort to set-up and maintain a working database. For the Organization, allocating time to the benchmarking process was seen as problematic. It currently has only one financial controller who is involved in compiling and producing various progress reports for all projects. Additional responsibilities to track and maintain a benchmarking database would be too onerous for him alone. The Organization would therefore have to commit or hire additional personnel to maintain and update this database. In benchmarking performance, the DES projects would be better suited as their contexts are similar. For building mechanical projects, building type, budget and scope, procurement mode and other contextual factors would have to be included in order to compare similar projects. This speaks to the need for a large pool of data, which is rigorously acquired over time.

Lastly, in developing additional metrics to assess the performance of BIM implementation, there is a need to establish metrics that are directly related to the organization’s type, position in the supply chain and sphere of influence. By evaluating the predictability of these metrics the performance of BIM implementation could be better evaluated. This can complement maturity models, which rely on more qualitative measures to evaluate capability evolution within an organization.

7 Conclusion

The emergence of BIM has exacerbated the need to holistically consider the benchmarking and performance assessment process within the construction industry. Performance, impact, ROI,
capabilities and maturity all need to be taken into account when assessing the BIM implementation process. While increasing evidence of BIM’s perceived and measured impact on project delivery is fueling its growth across the construction industry, many issues remain around establishing non-spurious relationships in its assessment. Past work has attempted to establish some relationships between capabilities, the use of BIM and its impact on performance, such as productivity, cost, schedule and quality. However, the scope of analysis of these works have been limited to the project context (Khanzode et al. 2007; Giel and Issa 2011; Barlish and Sullivan 2012) or to the organizational context (Coates et al. 2010).

This article has presented an evolutionary approach, supported by specific metrics, to benchmarking and performance assessment that bridges both the project and the organizational contexts to help an organization evaluate the performance of and inform its BIM implementation process. It has specifically looked at the predictability of KPIs across time as an indicator of performance. By evaluating the evolution of predictability of certain metrics across eight different projects, the research team laid the ground work for the assessment of the BIM implementation process from a quantitative perspective, which could support maturity modeling and capability assessment. While limited, the analysis of the data sample has allowed us to highlight that indicators, such as BIM costs and labor productivity, were seen as becoming more predictable across time. Other indicators, such as scope and quality were inconclusive, mainly due to the lonely setting in which BIM was implemented by the Organization. This speaks to the need to establish collaborative BIM environments to fully benefit from the improvements in project performance highlighted elsewhere. Future work could look into refining the approach presented here, evaluating the interactions between the various KPIs and investigating other KPIs to support this process.

This article does not attempt to establish a clear causal relationship between the use of BIM and project performance. Indeed, the limitations of this work lie in controlling for all variables that define the project context. Creating a set of generalizable metrics is near impossible and it is why no causation is infirmed between BIM use and project outcome. In parallel, the productivity measures used in this research require further investigation, namely in refining the units of measurement and limiting them to the actual scope of modeling. The specific field of mechanical contracting was studied in the development of KPIs, however further work should look into establishing metrics for other fields of work. Lastly, the extent to which BIM was
implemented in the projects studied represents a limitation. Indeed, all the projects studied were performed in a lonely setting. This speaks to the current state of the market in Canada and the difficulty the Organization is having in working in an integrated environment.

8 Acknowledgments

The research team is indebted to the Organization for their time and generosity in giving access to all relevant information to perform this research.

9 References


Kam, C., Rinella, T., Mak, D., and Oldfield, J. 2012. BIMSCORE: GPS for BIM Navigation, University of Southern California, Los Angeles, CA, pp. 63-78.


Khanzode, A., Fischer, M., and Reed, D. 2008. Benefits and lessons learned of implementing building virtual design and construction (VDC) technologies for coordination of mechanical, electrical, and plumbing (MEP) systems on a large healthcare project. ITCon Vol. 13(Case studies of BIM use): 324-342.


<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KPI: COST</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cost predictability</strong></td>
<td>Predictability of budget compared to actual project costs</td>
<td>(CII, 2013), (Egan 1998), (Khanzode et al., 2008), (Kunz and Fischer, 2012), (Rankin et al., 2008), (Suermann, 2009)</td>
</tr>
<tr>
<td><strong>Cost per unit</strong></td>
<td>Average project cost per unit produced (tendered and actual)</td>
<td>(Rankin et al., 2008) (Suermann, 2009)</td>
</tr>
<tr>
<td><strong>Cost for defects</strong></td>
<td>Cost of labor and material to rectify defects and rework</td>
<td>(Kunz and Fischer 2012), (Rankin et al., 2008)</td>
</tr>
<tr>
<td><strong>KPI: TIME</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Schedule Predictability</strong></td>
<td>Predictability of planned schedule compared to actual project duration.</td>
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<td><strong>Time per unit</strong></td>
<td>Average time per unit produced (tendered and actual)</td>
<td>(Rankin et al., 2008)</td>
</tr>
<tr>
<td><strong>Time for defects</strong></td>
<td>Time spent to rectify defects and rework</td>
<td>(Rankin et al., 2008)</td>
</tr>
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<td><strong>KPI: PRODUCTIVITY</strong></td>
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<tr>
<td><strong>Direct &amp; indirect Labor</strong></td>
<td>Dollars per unit and units per hour performed of direct &amp; indirect labor</td>
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<td><strong>Prefabrication</strong></td>
<td>Amount of off-site prefabrication performed</td>
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<td><strong>KPI: QUALITY</strong></td>
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<td>Total number of deficiencies (also related to cost and time)</td>
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<td>(Egan, 1998), (Rankin et al., 2008)</td>
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<td><strong>Lost Time</strong></td>
<td>“The amount of time lost to incidents measured against the hours worked during Construction” (Rankin et al., 2008)</td>
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<td><strong>KPI: SCOPE</strong></td>
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<td><strong>RFI - Quantity</strong></td>
<td>Quantity of RFIs</td>
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<td><strong>CO cost and quantity</strong></td>
<td>Quantity and cost of COs as a % of project costs</td>
<td>(Barlish and Sullivan, 2012), (Giel and Issa, 2011) (Khanzode et al., 2008)</td>
</tr>
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<td><strong>RFI - Response Latency</strong></td>
<td>Average response latency for RFI in a project</td>
<td>(Kunz and Fischer, 2012)</td>
</tr>
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<td><strong>Avoidance costs</strong></td>
<td>Estimated cost of conflict resolution and avoidance through BIM</td>
<td>(Giel and Issa, 2011)</td>
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<td>KPI: ORGANIZATIONAL</td>
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<tr>
<td>-----------------------------</td>
<td>------------------------------------------------------------------</td>
<td></td>
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<tr>
<td>Profit</td>
<td>Profit margin on projects</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Coats et al., 2010)</td>
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<tr>
<td>Client Satisfaction</td>
<td>Level of Client satisfaction with services</td>
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<td></td>
<td>(Egan, 1998), (Rankin et al., 2008), (Suermann, 2009)</td>
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<tr>
<td>Repeat Business</td>
<td>Number of contracts obtained from the same client</td>
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<td></td>
<td>(Coats et al., 2010)</td>
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Table 2 – Description of selected DES projects

<table>
<thead>
<tr>
<th></th>
<th>Project 01-A</th>
<th>Project 01-B</th>
<th>Project 01-C</th>
<th>Project 01-D</th>
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<td><strong>Description</strong></td>
<td>Small municipal DES project</td>
<td>Large institutional (university) DES project - Phase 2</td>
<td>Medium municipal DES project</td>
<td>Large institutional (university) DES project - Phase 3</td>
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<td>(10/11-02/12)</td>
<td>(09/12-03/14)</td>
<td>(08/14-09/15)</td>
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<td>DBB</td>
<td>DBB</td>
<td>DBB</td>
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<td>None</td>
<td>None</td>
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<td>8 ETS</td>
<td>11 ETS</td>
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<td>$1M</td>
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<td>• Modeled all Energy Transfer Stations</td>
<td>• Modeled all Energy Transfer Stations</td>
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<td></td>
<td></td>
<td>• Laser-scanned all mechanical rooms</td>
<td>• Initiated off-site prefabrication</td>
<td>• Laser-scanned all mechanical rooms</td>
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<td></td>
<td></td>
<td>• Clash detection with existing mechanical systems within rooms</td>
<td></td>
<td>• Clash detection with existing mechanical systems within rooms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• On-site prefabrication from spool drawings</td>
<td></td>
<td>• Off-site prefabrication</td>
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Table 3 – Description of selected building mechanical projects

<table>
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<tr>
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<th>Project 02-A</th>
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<th>Project 02-C</th>
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<td>6 story institutional (health-care) building</td>
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<td>Renovation of large mixed-used commercial building</td>
<td>3 story industrial building</td>
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<td>$5,3M</td>
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<td>• Modeled all building services (HVAC, Fire Protection, Plumbing, Electrical, etc.) to perform clash detection</td>
<td>• Obtained design models</td>
<td>• Modeled all mechanical rooms</td>
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<tr>
<td></td>
<td></td>
<td>• Targeted areas with most potential for conflict (shafts, ceiling spaces, etc.)</td>
<td>• Performed detailed modeling of mechanical penthouse</td>
<td>• Off-site prefabrication from spool drawings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Full prefabrication of mechanical penthouse</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Used as a coordination tool with sub-supply chain (HVAC and Electrical)</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1 - Benchmarking and performance assessment approach

Figure 2a - Cost - Cost predictability - DES projects - This graph illustrates positive values across the selected DES projects. Total project cost and labor costs are more predictable for projects having implemented BIM than for the non-BIM project. This can be interpreted as BIM potentially having a positive effect on ensuring better cost predictability on the total project cost and labor costs for DES projects.

Figure 2b - Cost - Cost predictability - Bldg. projects - This graph illustrates both positive and negative variability across the selected Bldg. projects. The predictability of total project costs is very good for both project 02-C and 02-D as is the predictability of site supervision for project 02-C. On the other hand, the other indicators show considerable variability. Given the limited sample, the impact of BIM on cost predictability on the selected budget items for Bldg. projects is inconclusive.

Figure 3 - Cost - Cost of BIM / Total cost of labor – This graph illustrates the variability between actual and estimated cost of BIM as a percentage of total cost of labor for all eight projects. One way to interpret this graph is as the Organization gains experience with deploying BIM in their projects, they are rapidly becoming better at evaluating the cost of BIM, hence the difference between actual and tendered costs are becoming lesser.

Figure 4 - Scope - Total Cost of CO / Total cost of work and Qty. of COs - This graph illustrates the cost of COs in relation to total cost of work as well as the quantity of COs. No clear relationship between quantity of COs and their cost implication exists. There is no discernible trend in the reduction of COs and their cost impact across the selected BIM projects. One of the root causes of this may be the lack of integrated setting in which BIM is deployed at the project level, the Organization being the “last to BIM” and not being able to influence upstream decisions as well as the limited scope of BIM use on these projects as reported during our interviews with the organization.

Figure 5 - Productivity - Labor cost per unit – These two graphs illustrate the cost of labor per unit as a measure of productivity in the field. Labor productivity predictability is better for the DES projects than the bldg. projects.

Figure 6 - Productivity - unit per time - These two graphs illustrate productivity rate for both project streams. The predictability of productivity rate in both streams is highly variable across projects, with projects 01-B, 02-A and 02-B having a lower actual productivity rate than estimated, while actual productivity rates for projects 01-A, 01-C, 01-D, 02-C and 02-D are superior to estimated productivity rates.

Figure 7 - Productivity - BIM cost per unit – These two graphs illustrate the cost of BIM per unit as a measure of productivity in the modeling process. It also illustrates the average actual cost of BIM per unit which can serve as a baseline for comparison for future projects to assess the efficiency and progress of BIM implementation.

Figure 8 - Schedule - Predictability of Labor duration – This graph illustrates the conformance of project duration across all 8 projects. Projects 01-B, 02-A, 02-B have actual durations that are longer than estimated in terms of total project hours.
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These two graphs illustrate the cost of labor per unit as a measure of productivity in the field. Labor productivity predictability is better for the DES projects than the bldg. projects.
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