

EVALUATING THE BENEFITS OF BIM FOR SUSTAINABLE DESIGN – A REVIEW

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The application of Building Information Modelling (BIM) to construction projects has the potential to enhance the quality of information provided for making critical design decisions regarding a building's environmental impact. However, the provision and utilisation of such information has yet to be effectively exploited in most instances and disconnections between BIM methodologies and sustainable design practices within construction companies are evident. But the fundamental aspects of integrative design, multiple stakeholder collaboration, common goal-setting, the quick efficient presentation of complex concepts to enable fast and effective decision-making, and an emphasis on dialogue between stakeholders are as fundamental to sustainable design processes as they are to BIM enabled construction. Differing perceptions and misaligned expectations of the benefits and expected outcomes of BIM and sustainable design adoption go some way to prevent a synthesis between the two approaches. There have been attempts to develop methods to calculate and quantify the benefits of BIM and related information system adoption but existing methods of analysis lack industry acceptance and fail to provide a principal framework methodology that can measure comparable data across multiple projects. An in-depth review of existing literature surrounding frameworks and methodologies to evaluate and analyse the benefits of BIM and sustainable design is presented. The issues surrounding the implementation of BIM alongside sustainable design practices and the inherent problems associated with attempting to evaluate benefits in a purely quantitative fashion are reviewed. Limitations of past research studies in BIM benefits measurement are discussed and the development of a broader framework that incorporates both quantitative measurement and a more qualitative understanding of the process of integrating BIM and sustainable design to measure the potential of BIM for sustainability are suggested.

Keywords: BIM, sustainable design, benefits evaluation.

INTRODUCTION

The built environment is recognised by policy-makers and stakeholders as having a significant role to play in reducing carbon emissions and achieving sustainable development (DEFRA, 2005; IPCC, 2007). Assessment and certification methods are consistently extolled as an important means by which to achieve such targets with the predominant and most established method used within the UK being the Building Research Establishment Environmental Assessment Method (BREEAM). However,

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the effectiveness of these tools at engendering the ideal notions of sustainability advocated by some authors is refuted due to the failure to address underlying industry-wide organisational issues and a lack of a definitive understanding of what sustainability really is and means to the construction industry.

Within this paper sustainable design is defined as the processes and practices of design that contribute to sustainable patterns of living throughout the built environment, based on the dominant 'triple-bottom-line' approach. A paradigm shift from static notions of building performance to the regenerative contribution the built environment can make to the social, ecological and economic health of the place in which it functions is the ideal. To achieve this, common understanding amongst diverse stakeholders is required; a move from an isolated and static understanding of building performance in terms of design to an expansive and dynamic dialogue that encourages an understanding of the implications of the building lifecycle on occupant lives and business success will engage and maintain stakeholder commitment (Clements-Croome et al. 2004; Cole 2011; du Plessis & Cole 2011).

However, the highly fragmented design and construction process consisting of differentiated stakeholders with disparate approaches and specific project goals that are influenced by varying professional practice codes make interdisciplinary work difficult at early stages of design (Feige et al. 2011). Consequently the adversarial culture associated with traditional construction promotes self-interest and a necessity for voluntary and institutional mechanisms to ensure compliance in terms of sustainability. The current culture allows stakeholders to make decisions that reflect their own interests and select the approach that gives the best solution for them to meet organisational performance rather than building performance within the context of place. With current legislation stipulating the minimum requirements for sustainability, this is invariably perceived by project teams as supplementary to the primary goals of on-time and within budget. Cole (2012) refers to Robinson (2004) and the suggestion that for sustainability to become a meaningful concept it will require 'new concepts and tools that are integrative and synthetic, not disciplinary and analytic; and that actively creates synergy, not just summation'.

An exposition of the role of BIM as a process to facilitate a change in the prevailing perceptions and practices of sustainable construction, and why the development of performance measurement frameworks requires more than the assessment of discrete technical performance for it to become meaningful and beneficial to both organisational performance and building performance is now presented.

NORMALISATION OF SUSTAINABILITY VALUES THROUGH ASSESSMENT METHODS

A common theme throughout much of the literature is that the ideal notions of sustainability are subject to interpretation and the normative effect of standardised assessment methods such as BREEAM, in part, determine practitioner perceptions of sustainability and facilitate, or conversely impede dialogue amongst stakeholders over core values that shape and change the expectations of the environmental performance of buildings.

Schweber (2013) considers the effect of BREEAM as a process and its ability to change prevailing perceptions and practices regarding sustainable construction. The presiding debate centres on the notion that along with top-down policy debate concerning the most comprehensive definition of sustainability within a wider

domain, the specification of new standards and assessment methods within the construction industry contribute to a bottom-up definition. How such standards and assessment methods achieve this and to what extent were analysed through the systematic comparison of assessment processes across eight case studies from three firms who offer BREEAM assessments and one large engineering consultancy firm who contributed to the study in their capacity as project managers. Each firm provided two cases; one considered successful and one where lessons could be learnt and three types of relationships between assessment method and design and construction processes were determined: projects in which high integration occurred, projects in which moderate integration occurred, and projects in which BREEAM was considered a bolt-on process that had relatively little impact on the design and construction processes. Data consisted of 49 semi-structured interviews with assessors, clients, architects, project managers, design managers, and specialist engineers, and documentation produced by the assessment process. And the findings suggest that while BREEAM provides an established measurement framework for a building's environmental impact with relative ease of comprehension for those unfamiliar with sustainable design, the technique required to aggregate complex, heterogeneous and technically discrete specifications into a single score fails to engage clients in dialogue over the core values associated with specific design decisions that constitute a 'green building'. Also, the highly bureaucratic demands associated with some credits that require client involvement, such as community engagement, undermine client engagement with the process as a whole and although BREEAM was successful in translating complex ideals of sustainability to project team members who would otherwise not engage in such discussions, practitioners familiar with sustainable design generally perceived the assessment method as inadequate in embodying the new rationality purported by many authors (Du Plessis & R. J. Cole 2011; Moffatt & Kohler 2008).

The study also identifies the lack of accountability associated with some credits over which the design team have no control yet the linear technical approach to building assessment results in a loss of that credit, thereby weakening the internalisation of BREEAM as a measure of practitioner practice or challenge to existing perceptions. The study concludes that it is important to consider the impact of tools and assessment models and the taken for granted perceptions of standards on 'best' practice. It would appear that the assessment regime defines and permits decision-making toward minimum standards that fit best within existing organisational practice and that the value of BREEAM as an assessment model to achieve goals in line with revised definitions of progressive sustainability definitions may be limited.

BUILDING INFORMATION MODELLING

There have been a number of management methods and change frameworks to address inefficiencies within the construction industry in a bid to achieve 'best' practice, many of which were developed in response to reviews and reports (Green 2011). A key driver for UK mandated BIM strategy is the 2011 Government Construction Strategy, that calls for the replacement of "adversarial cultures with collaborative ones" and demands "cost reduction and innovation within the supply chain" as well as criticising the industry for failing to take advantage of the "full potential offered by digital technology". It would appear that BIM enabled construction work has come closest to a mandated collaborative working methodology; facilitating the redesign of organisational functions and processes toward integrative design, multiple stakeholder collaboration, common goal-setting,

the quick efficient presentation of complex concepts to enable fast and effective decision-making, and an emphasis on dialogue between stakeholders (Ahmad et al. 1995). Aspects of working methods that are purportedly required to meet already established BREEAM assessment criteria and a paradigm shift in the approach to sustainability advocated by many commentators (Du Plessis & Cole 2011; Cole 2011; Cole 2012). Using BIM may change the regime in which decisions are defined and permitted in line with progressive sustainability goals but there is a significant need to understand BIM as a 'systemic' (Taylor & Levitt 2004) and 'unbounded' (Harty 2005) innovation to avoid ineffective implementation because the perceived benefits of adopting IT enabled collaborative tools can only be realised when the antecedent conditions required to successfully implement IT are in place and the organisation is in a state of 'readiness' to synergise (Taylor, 2007).

Successful implementation at project-level requires organisational-level strategic planning that considers issues of technical support in terms of hardware and software rationalisation for cost effective use, critical management support in terms of challenging embedded processes, a supportive workplace environment in the form of BIM champions to share experience and skill, and an understanding of users' individual-characteristics so that the framework processes offered can be effectively applied (Peansupap & Walker 2006). Consequently, considerable mutual adjustment is required to enable successful technology adoption in inter-organisational collaborations and teams to bridge the boundaries between design, construction and operation, which is determined by a variety of factors: stakeholders attitude toward the technology, corporate culture, relationships between companies, project characteristics, industry-wide issues of legal standards currently employed, communication density, organisational barriers and individual's resistance to change (Dossick & Neff 2010; Nitithamyong & Skibniewski 2006; O'Brien 2000). These are factors that may affect the outcomes specified in many BIM assessment methods as well as sustainability assessment methods.

BUILDING INFORMATION MODELLING PERFORMANCE ASSESSMENT

Methods to measure implementation success referenced in this paper predominantly have a myopic focus on financial performance indicators with the majority of existing studies conducted in the US where there is no mandated BIM strategy. As such, these studies predominantly examine benefit measurement methods for the purpose of constructing a business case for practitioners and owners to invest. And although case studies realise benefits they provide no formalised repeatable measurement framework to determine best practice and/or process improvement.

The McGraw Hill Report is based on an internet survey of 2,228 completed responses from 598 Architects, 326 Engineers, 817 Contractors, 118 owners, 73 Building product manufacturers and 296 other industry respondents to gauge the practitioner perception of the value of BIM. 77% of users perceived a positive ROI on their investment, 87% were experiencing a positive ROI and 93% believed there is more value to be realised in the future. The report also contains four case studies one of which, for an 11-storey 540,000 square-foot biomedical facility, bases its success on an integrative approach, engaging early with the design team with contractor and owner inclusion and an extensive design and preconstruction process to develop a data management process. It led to a reduction in RFI's of 37% and a reduction of change orders of 32% throughout the project compared with the similar non-BIM enabled

previous project. The project team also experienced an estimated 50% reduction in labour and work schedule as a result of BIM though the specific role of BIM is not discussed.

The second case study, for a Health Science Centre, determined the success of BIM through completion within budget. The project was awarded on a second round tender and BIM was used to model the project in advance to give a firm understanding of project costs to compete in a 'hard bid environment'. An understanding of the organisational processes that took place to make the technology adoption successful would provide a valuable contribution to the industry as a whole.

The third case study, for a medical health centre, reported success in terms of improved scheduling and cost savings however the project narrative offers a more interesting insight into the processes required to achieve the identified success measures; faster decisions and streamlined processes as a result of the technology were predicted but there was resistance against technology specification in fear of constraints around creativity and productivity. A clear strategy of interdisciplinary information exchange was determined without software specification. Prior to commencement of on-site activities the project team had produced over 25,000 electronic design documents and eight servers were used to enable 50 companies creating files across the US to have real-time data access from any location.

The final case study of a high-explosives material pressing facility measured success through clash detection of extensive process piping, operating equipment and electrical and control systems. Cost savings of \$10 million were attributed to the technology. The project specification was to optimise spatial coordination so it is logical that the performance measure was the number of clash detections.

Indicating a need for a consistent cost-benefit benchmarking framework associated with BIM process enhancements and innovations as a motivator for adoption Becerik-Gerber & Rice (2010) conducted a survey to gauge the perceived value of BIM in the U.S building industry with specific focus on tangible benefits and costs at project-level. 424 respondents answered questions regarding; the size and type of projects BIM was used on; the type of software used; the tasks the software is used for; the number of projects it is used on; and the ratio of total cost spent on software, hardware, maintenance and training to overall net revenue. Hardware and software costs contributed most to overall expenditure whereas the majority of respondents reported spending less on software upgrades, hardware maintenance costs and training. Around 41% of total respondents realised an increase in overall project profitability with firms having more experience reporting higher returns. 48%, 47%, and 58% of respondents reported scheduling improvements during the design, bid preparation and construction phases, respectively. What effect independent variables such as software upgrades, hardware maintenance and training have on the dependant variables such as perceived project profitability is unknown and maybe a significant interdependent variable.

Giel et al. (2010) conducted a study based on the premise that a company's capacity to finance virtual design and construction (VDC) goals is determined by the owner's willingness to pay additional fees. Two case studies were conducted and compared based on BIM-preventable change orders and the associated schedule differences: Case Study One compared two commercial warehouse projects of around \$8 million and 365 days duration with savings of 36.7% in the non-BIM project and 16.2% in the BIM project; Case Study Two compared two concrete condominium projects of

around \$40 million and around 600 days duration with ROI's of 1653.9% and 299.9%. However it is difficult to determine whether the scheduling improvements were entirely attributable to the use of a BIM-based model.

Barlish & Sullivan (2012) recognise the highly contextual domain in which BIM benefits measurement is set and the void of a balanced repeatable framework for BIM implementation that considers both monetary and managerial outcomes. The paper offers a reductive and positivist analysis that purposefully ignores the qualitative aspects of BIM implementation in order to develop a BIM GO/NO-GO decision mechanism through net benefit analysis. The framework is in response to the numerous IS evaluation methods that are reactive and prescriptive, relying on individual perceptions of value and a matrix of potential BIM benefits was composed from a review of existing literature. The most quantifiable and generalizable returns were determined; schedule, change orders, and RFIs. Returns on investment of reduced change orders and improved scheduling were 70% and 53% respectively and alongside quantifiable calculations the study conducted individual interviews with Project Managers and Coordinators to gauge the contextual information of BIM implementation rather than the interdependency. They reported an increase in contractor attendance at coordination meetings, a diminishing BIM software learning curve and decreased contractor accountability from BIM utilisation. Whether accountability was decreased as a result of increased attendance was not examined nor if the diminishing learning curve could be diminished further through increased expenditure on training.

In summary the metrics chosen in each study only provide an indicator of improvements; they do not provide a narrative of improvements, interdependencies of process change and benefits as a result of technologies, training or information quality, and/or lessons learnt. For example, Perceived ROI though important to understand the industry perception of the benefits of BIM, cannot replace actual ROI and the variables that can be adjusted to improve it. Also, measures identified are specific to different disciplines; RFIs are used as a measure of improved quality of information however the number will vary depending on project and participant context; productivity through drafting and documentation though a direct benefit to design teams are not as effective for contractors whose work focusses less on modelling or drafting (Lee et al. 2012). Consequently, shortened project duration is often used as a metric to determine success during construction, however there are many other factors that contribute to improved scheduling such as construction methods and equipment, number of personnel on site, and management quality (Lee et al. 2012).

'What gets measured, gets attention' (Eccles 1991) and can obstruct good judgement (Pfeffer & Sutton 2000) and the oversimplification of complex problems into localised improvement initiatives can reduced overall performance (Owen & Huang 2007) so it is important that the relevant measures identified contribute to the quality and productivity of the IS function and the larger organisational performance by providing feedback to manage and improve IS function to meet the needs of the organisation/project (Myers et al. 1997). Perhaps it is more pertinent to develop benchmarks that are used as a proxy to determine efficiencies, or lack thereof, to track and mitigate implementation failure. In which case metrics alone cannot determine the success of BIM; qualitative analysis of its role must supplement quantitative factors to develop an iterative measurement and analysis framework of existing performance to improve BIM capabilities and achieve differentiation.

BUILDING INFORMATION MODELLING & SUSTAINABLE DESIGN

During the design and preconstruction stages of a building the most significant decisions regarding sustainable design features can be made (Azhar et al. 2011). Linking new approaches to simulation and analysis within sustainable design to enhanced coordination of information via BIM throughout the construction process allows both reduction of rework and waste and the realisation of ‘designed-for-performance’ new buildings and infrastructure through dialogic engagement of stakeholders.

(Krygiel & Nies 2008) suggest BIM can assist in the following areas of sustainable design: building orientation (selecting a good orientation can reduce energy costs), building massing (to analyse building form and optimize the building envelope), day-lighting analysis, water harvesting (reducing water needs in a building), energy modelling (reducing energy needs and analysing renewable energy options can contribute to low energy costs), sustainable materials (reducing material needs and using recycled materials), and site and logistics management (to reduce waste and carbon footprints). Design options for sustainability can be tracked and studied in a model along with spatial data to geographically locate and import building site information to place it within context and to contribute to an understanding of issues relating to climate, surrounding systems and resources. The building can then be adjusted and engineered using real coordinates to reduce the impact on and utilise sustainably the surrounding environment to reduce energy requirements, for example solar orientation (Hardin 2011).

Literature regarding the integration of sustainability tools with BIM has shown improvement in assessment processes and effectiveness through comprehensive and efficient data extraction that reduces the time, effort and cost of an assessment, multi-disciplinary sustainable design decisions made at the design stage that enable relatively fast and inexpensive improvements to be made relative to changes made during and after construction, and a reduction in human error through the use of standardised and authorised information. Azhar et al. (2011) demonstrated the relationship between BIM and the LEED rating process making four conclusions: no explicit relationship exists between the LEED® certification process and BIM-based sustainability analyses due to inadequate software integration; up to 17 LEED® credits and 2 prerequisites may be documented using results generated by BIM-based sustainability software directly, semi-directly or indirectly; compared to traditional methods BIM-based sustainability software saves substantial time and resources; discrepancies between the software and manual results were mainly due to an inadequately developed model.

During the life cycle of a large commercial structure Scheuer & Keoleian (2002) found that approximately 95% of energy consumption and emissions occur in the operational phase. Through the use of highly energy efficient materials and building operation optimisation technologies the impacts to life cycle energy and emissions consumption from the operational phase can be shifted back to the material production and construction phase (Blanchard & Reppe 1998). Integration of LCA software and BIM software to automate this process will not only allow efficiencies in LCA assessment procedures but also enable design changes to be made prior to construction and assist building management in the optimisation of a building’s environmental footprint throughout its operation (Russell-Smith & Lepech 2012).

There are a number of other BIM-based tools and systems that have been and are being investigated and developed to tackle a range of sustainability concerns across the entire construction process from design inception to Facilities Management and lifecycle analysis (Azhar et al. 2009; Capper 2012; Che et al. 2010; Geyer 2012; J. Park & Kim 2012; Schlueter & Thesseling 2009). And whilst these technologies may assist in achieving the outcomes stipulated by sustainable assessment methods, the mechanistic and linear approach required to achieve credits fails to capture, and may even prevent, the more humanistic and developmental benefits BIM may bring in terms of dialogic stakeholder engagement, common understanding and internalisation of sustainability values that add value to the end user through continuous analysis and discussion of sustainability throughout the design and construction process with relevant stakeholders.

CONCLUSIONS

The metrics chosen in most studies only provide an indicator of improvements; they do not provide a narrative of improvements, interdependencies of process change and technologies, training or information quality, and/or lessons learnt. Static notions of best practice neglect aspects of cultural environment, and social interaction and negotiation that could affect not only the outcomes but also the constructs themselves.

Practitioners are therefore encouraged to follow routine algorithms within a dominant culture of compliance rather than to adopt innovative solutions to the inherently complex problems of organisational development and sustainable design that standardisation should support. Exemplary buildings are achieved but they are accomplished in spite of the current traditional methods not because of them. BIM methodologies and tools, through the standardisation of practices and processes, may free practitioners from the bureaucracy of traditional construction capacitating meaningful dialogic stakeholder engagement, practitioner discretion over design and improved decision-making by eliminating the restrictive conditions associated with traditional construction. But if performance analysis remains reduced to abstracted, mechanistic best practice algorithms, the organisational development and sustainable design benefits that BIM enabled construction can offer may not be realised.

Mechanistic conceptions of measurement methods across a disparate group of construction practitioners are difficult to achieve when the change required to improve is constrained by embedded practice and professional structure and different path dependencies themselves have different embedded practices and professional structures. BIM methodologies and tools go some way to address these issues but to realise the benefits, assessment methods must be more holistically diagnostic in order to identify the conditions required to successfully implement appropriate techniques relevant to the organisation and projects. By accounting for these conditions, BIM may produce renewed expectations and broader ranges of opportunities that should inevitably produce improved organisational capabilities and subsequently value-added sustainable design.

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