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A NOVEL FRAMEWORK FOR BIM ENABLED FACILITY ENERGY MANAGEMENT – A CONCEPT PAPER

Firas A. Al-Shalabi[1], and Yelda Turkan[1, 2]
[1] Department of Civil, Construction and Environmental Engineering, Iowa State University, USA
[2] yturkan@iastate.edu

Abstract: Building Information Modeling (BIM) enabled facility management has gained increased interest both in academia and industry. Previous research has shown the importance of having dynamic BIMs that can react and interact with real-time data obtained from building sensors. The other sought benefits of BIM such as improving workforce efficiency, proactive maintenance planning and improving maintenance records, which would lead to reduced energy and water consumption, are also acknowledged both by the academic community and the industry practitioners. However, BIM implementation for facility energy management activities, specifically for energy use monitoring, has not yet been explored, and one of the main reasons pertain to not having standards for BIM to be effectively used for facility energy management tasks. This paper provides a comprehensive literature review on BIM implementation and BIM requirements for facility management and facility energy management related tasks. Also, it proposes a conceptual framework that enables to achieve dynamic BIM for building energy use monitoring activities. The proposed framework connects BIM database with building energy management systems, while enabling BIM to act as a central data repository and a visualization tool to achieve energy use monitoring related tasks. Finally, it summarises the challenges to achieve dynamic BIM, and concludes with the expected benefits of implementing dynamic BIM for building energy management as well as recommendations for future research.

1 INTRODUCTION

Energy Management is one of the most important tasks among Facility Management (FM) responsibilities. Building Energy Management Systems (BEMS) are used to operate, control and monitor energy use in buildings. BEMS are also used to manage buildings' environment and to control their heating, cooling and lighting systems. However, many of BEMS capabilities, such as automated data sharing, are not yet fully achieved.

There is a growing interest in the Construction Industry in using Building Information modeling (BIM) throughout buildings' life cycle including Facilities Management (FM) practices. BIM implementation for FM applications, including energy management tasks, is considered an emerging field. Many benefits of implementing BIM in FM are sought during later phases of buildings' life cycle. Those benefits include the ability to extract and analyze data for various needs that could support and improve decision making process, thus improve the energy performance during Operation and Maintenance (O&M) phase.

In this paper, a novel framework is introduced, where BIM is used as central data repository for operating buildings and managing their energy performance. This framework aims to achieve a dynamic BIM that can act and react with BEMS and provide feedback to operators and building energy managers. This framework is part of a larger study that will be implemented for educational buildings in order to test its performance.

The paper is organized as follows; the next section gives background on current building operation and energy management practices including BEMSs. Section 3 then reviews current BIM uses and presents a novel framework for using BIM during building operations and maintenance phase. Section 4 focuses on the challenges that this framework would face and proposes solutions for each identified challenge. Section 5 draws conclusions and discusses future research needs.

2 CURRENT BUILDING ENERGY MANAGEMENT PRACTICES

Energy management is considered the top priority among the functional responsibilities in FM, followed by maintenance and repair (Sadeghifam et al. 2013; Underwood and Isikdag 2011; Yao 2013; Yiu 2007). Currently, tools such as Building Automation Systems (BAS) and BEMS are used to manage buildings' environment and control their heating, cooling and lighting systems, i.e. to perform building energy management tasks. Those systems are defined as a collection of microcomputer systems consist of Direct Digital Control (DDC) controllers and their control devices, which operate under supervisory control equipment or software collectively. Their abilities include sharing data with individual controllers for coordination and optimization, linking control processes, and performing operation tasks and reports (Doty and Turner 2009). BEMS are considered an essential source of information for building energy performance assessment that is used to optimize building energy performance as well as to fix any problems in building systems. However, many of BEMS capabilities, such as automated data sharing, are not yet achieved, and the current BEMS practices lack continuous data flow throughout facility life cycle (O'Sullivan et al. 2004) (Figure 1). Furthermore, data to the O&M phase is input manually, which results sometimes in inaccurate and incomplete information (Kelly 2013) that would require facility managers to re-enter the missing data they need to operate BEMS and guarantee optimal energy performance.

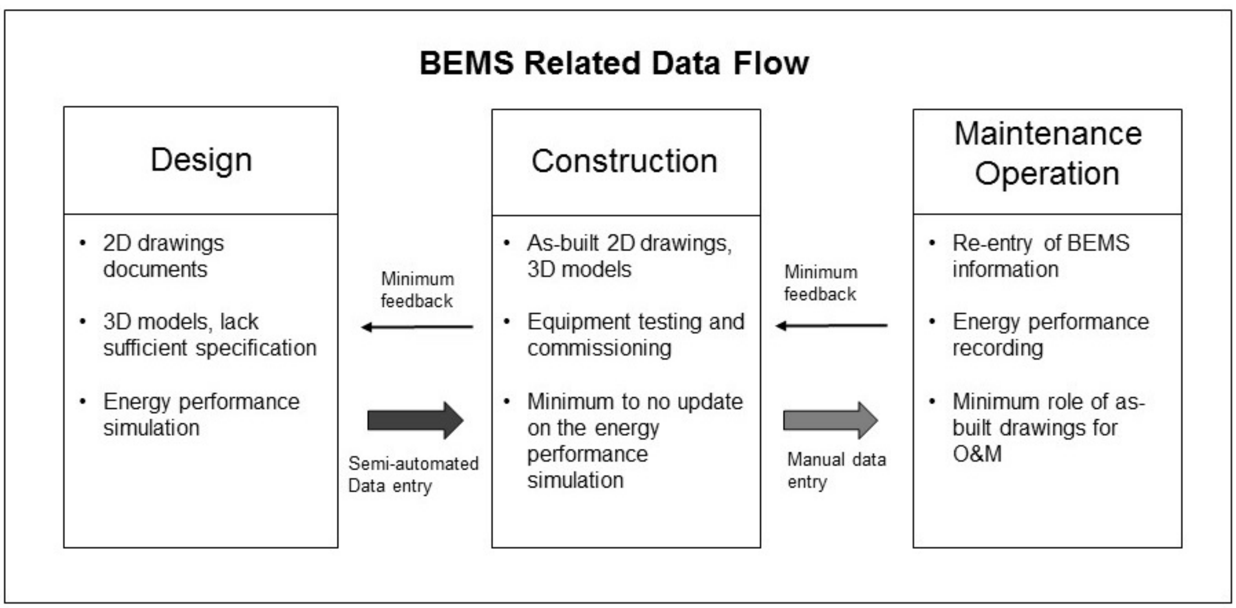

Figure 1: Energy management related data flow throughout building life cycle

Continuous feedback from BEMS during O&M is considered essential to maintain the planned operational and energy performances of buildings. In addition to imprecise commissioning and BEMS malfunctioning, not providing real-time data to BEMS are considered as the main reasons for buildings' performance deterioration. BEMS enable building energy performance monitoring, and help achieve energy savings of up to 40% (Claridge et al. 1994; Herzog and LaVine 1992; Salsbury and Diamond 2000). However, they are becoming more complex and difficult to operate for an average operator (Hyvärinen and Kärki 1996).

BEMS records and stores building energy use data collected from sensors (e.g., temperature, CO2, zone airflow, daylight levels, occupancy levels, etc.) as well as data from fault detection and diagnosis sensors (e.g. air handler units controls, HVAC systems, valves controls and fans controls). Those sensors are numbered and organized based on their location in the building, and presented in list format. Sensor outputs, energy performance metrics (i.e. energy consumption), and other building performance metrics are presented in 2D histograms, tables and lists of tasks or in similar formats (Figure 2). Furthermore, maintenance records and other facility documents are kept in separate systems, not in BEMS, plus all these software have their own data structure that are not compatible with each other (Wang et al. 2013). As a result, when BEMS shows a problem for one of the building elements, facility energy managers and maintenance personnel need to obtain further information associated with that particular element. This requires them to check other systems such as building maintenance and warranty records. Finally, after gathering all necessary data, the problematic element needs to be located within the building, which maybe a tedious task, especially if the element is located in an area congested with other building elements such as pipes, ducts etc.

Figure 2: BEMS user interface

Overall, this makes it cumbersome to evaluate energy performance of an entire facility by gathering data from separate systems (Pietruschka et al. 2010; Yao 2013). Furthermore, it limits the possibility to react to any changes or possible problems in the system on time. It also prevents from developing a proactive maintenance strategy, which may increase energy losses due to system defects. For example, it is estimated that about 30% of the energy in commercial buildings is wasted because of degraded and poorly maintained equipment (Granderson et al. 2011).

3 A NOVEL DYNAMIC BIM FRAMEWORK FOR BUILDING ENERGY MANAGEMENT

There is a growing interest in the Construction Industry in using (BIM) throughout buildings' life cycle including FM practices. BIM supports a collaborative approach throughout the project's life cycle phases and engages multiple stakeholders in the project including architects, engineers, contractors and the facility managers. Furthermore, BIM eliminates tedious and error prone data entry process, which leads to decrease/eliminate loss of project/facility information during project lifecycle (Figure 3) (Eastman et al. 2011).

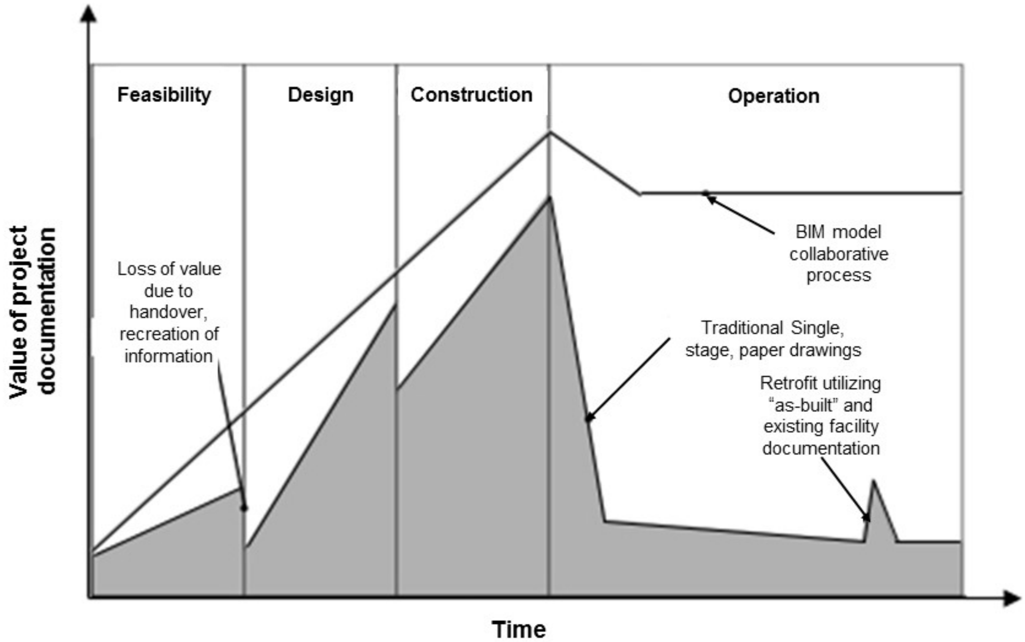

Figure 3: Documentation loss of value during project lifecycle (Eastman et al. 2011)

BIM implementation for FM applications, including building energy management, is considered an emerging field that lacks real case studies (Kelly 2013). However, most benefits of implementing BIM in FM are sought during later phases of buildings' life cycle, such as the ability to extract and analyze data for various needs that could support and improve decision making process (Azhar 2011). Furthermore, BIM in FM applications can help increase the efficiency of work order executions by providing faster access to data and by improving the process of locating various facility elements with its user friendly 3D interface (Kelly 2013). In addition, BIM implementation in FM and BEMS would help eliminate redundancy in data re-entry since BIM would act as a central data repository (Figure 4) that supports all activities throughout the buildings' life cycle from design to maintenance and operations (Fallon and Palmer 2007).

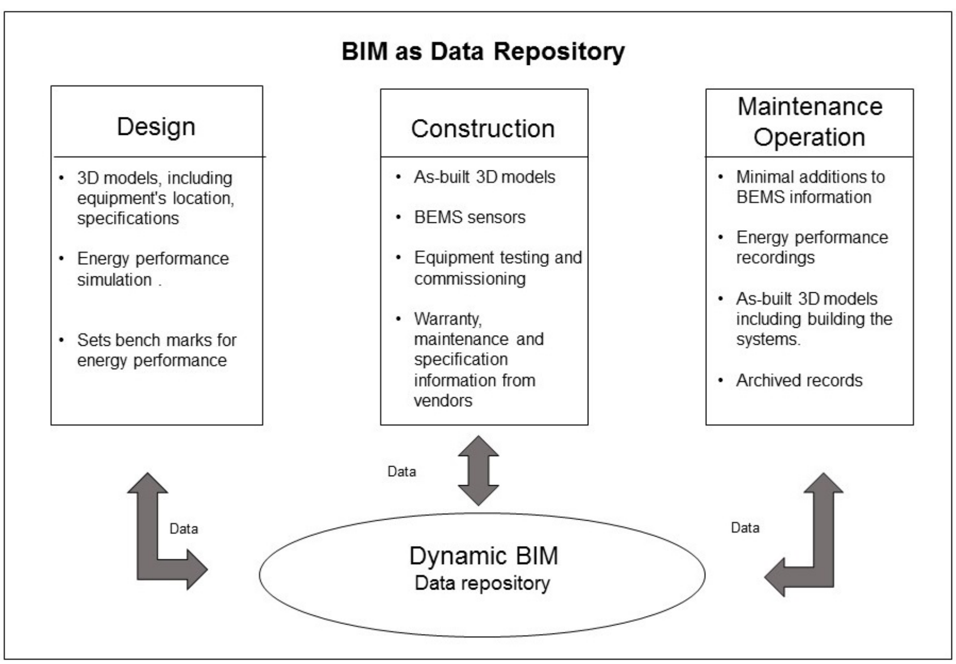

Figure 4: BIM as Data repository in buildings' life cycle

3.1 Dynamic BIM framework

BIM implementation for energy management activities has been limited to green retrofit modeling and design simulations. This maybe a result of unforeseen productivity gains that can be realized from reduced equipment failure as well as the productivity increases that maybe realized through an integrated platform (Becerik-Gerber et al. 2011). A suggested step forward would be to integrate energy use data with BIM database for building energy use monitoring (Muthumanickam et al. 2014) in order to achieve a dynamic BIM (Figure 5). Having dynamic BIM models that reflect actual as-built conditions and contain real time building information gained increased interest lately (Akanmu et al. 2013). A dynamic BIM model has the potential to provide improved documentation, minimize the cost of facility operations and maintenance, serve as a useful reference for future projects, and improve proactive maintenance planning (Chen et al. 2014; Teicholz 2013). This, overall, would lead to reduced energy consumption as a result of having well maintained, efficient mechanical equipment.

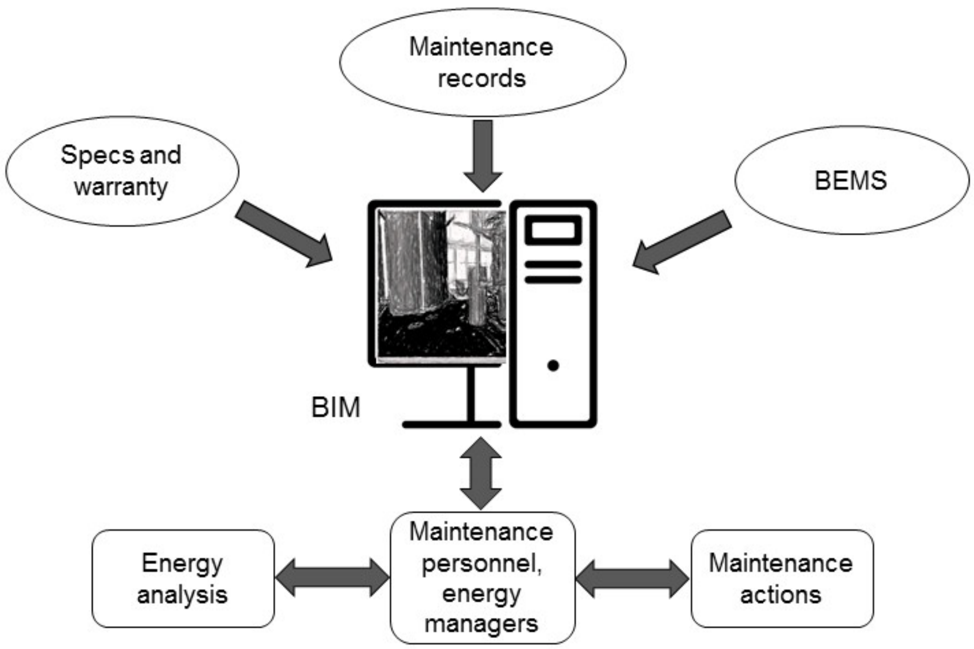

Figure 5: Dynamic BIM concept for FM

This paper proposes a novel framework that utilises dynamic BIM models containing real time building information obtained from sensors and BEMS to improve facility energy management activities (Figure 6). This framework aims to integrate BIM with BEMS systems using a programming application to enable industry foundation classes (IFC)-based BIM files read and update their database based on the BEMS live feed. Visualization of BEMS data in user friendly 3D BIM interface would enable facility energy managers to take timely actions about the problematic building elements, i.e. proactive maintenance, which would translate into energy savings.

In order to achieve the proposed framework, two programming applications will be developed; the first one is to link the BIM database with energy sensor output data, through BEMS, thus to visualize real-time energy use as color coded 3D models and to link it to each model element, where building maintenance and records of warranties and other information are stored. This would allow comparing the collected data with historical energy consumption data, the design or manufacturer claimed data and maintenance records simultaneously, which would help discovering any over consumption or flaws in the system in an efficient and timely manner. The second programming application will be developed to link BIM database with energy analysis programs, where energy consumption can be analyzed and over consumption can be detected.

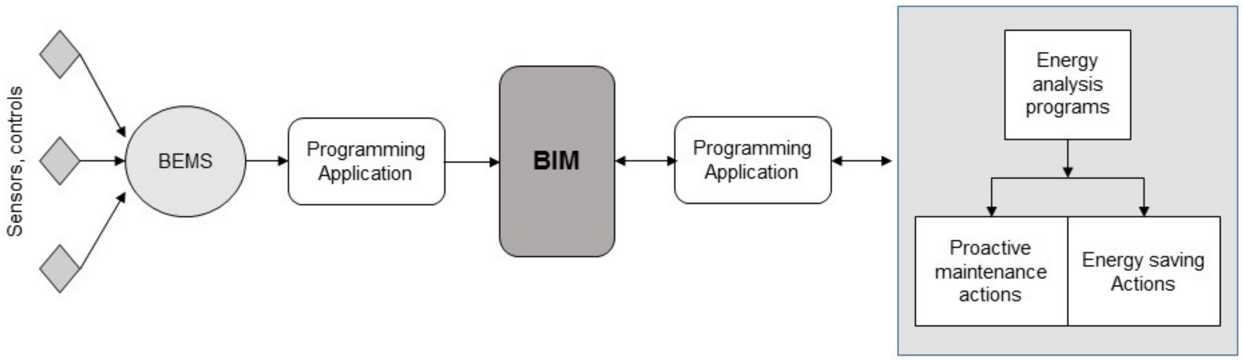

Figure 6: BIM - BEMS framework

Consequently, this should enable energy managers to detect any over consumption immediately, which would help them determine the reasons behind it faster. This would improve proactive maintenance plans and actions as it enables detecting defective or faulty equipment in a faster manner, so that they can be replaced immediately without causing more energy losses.

4 DYNAMIC BIM CHALLENGES

In order for BIM to be used in facility and energy management practices it needs to be dynamic; and that is, reflecting actual conditions of a facility and presenting real time building information. However, achieving "dynamic" BIM is faced by a number of challenges, which can be grouped into three main categories: (1) lack of guidelines for the necessary information required for BIMs to be used in building energy management related tasks; (2) inaccuracy and/or incompleteness of as-built BIMs; (3) interoperability issues between BEMS and BIM authoring tools (Laine et al. 2007). In this paper, a framework that connects BIM with BEMS is being introduced to help overcome one of these challenges, the interoperability issue.

The first obstacle, the necessary information required for BIMs to be used for building energy management tasks, has been addressed and stated in the literature. Becerik-Gerber et al. (2011) suggested that three types of energy management related FM data should be incorporated into BIM: (a) equipment and systems, (b) attributes and data, (c) portfolios and documents. However, specifications and details of this FM data, such as type of equipment that should be included in the model and attributes and the level of detail of the building model, were not described. Furthermore, the Pennsylvania State University computer integrated construction research program report (2013) suggested that the following items should be identified, documented and included in order to achieve dynamic BIMs: (a) type of building elements to be tracked (b) information display format (c) Level of Detail (LoD) required for each model element (d) properties and attributes of each element.

The second challenge pertains to inaccuracy and/or incompleteness of as-built BIMs. Several researchers suggested that early involvement of FM personnel in design and construction phases would be very beneficial for developing accurate and complete as-built BIMs (Teicholz 2013; Wang et al. 2013). However, such involvement remains limited due to lack of knowledge about BIM implementation for FM tasks (Kelly 2013), lack of specific data requirements (Becerik-Gerber et al. 2011; Kelly 2013), and interoperability issues (BIFM 2012). The issue related to inaccuracy of as-built BIMs (at object level), has been addressed both by researchers and industry practitioners. Several researchers emphasized the importance of having accurate and up-to-date as-built BIMs for FM tasks (Ahmed et al. 2014; Akinci 2015; Bosché et al. 2013; Son et al. 2014). Therefore, developing guidelines and requirements for BIMs to be used for building energy management practices is essential for achieving dynamic BIM and needs broader attention.

The third obstacle, interoperability issue, has been widely expressed both by researchers and industry practitioners. Interoperability enables to manage and communicate electronic data among collaborating firms, between different disciplines in individual companies and between different phases of a project, i.e. design, construction, maintenance and business process systems (Gallaher et al. 2004). Interoperability issues between FM and BEMS programs and protocols are common and well known. Furthermore, there are interoperability issues between BEMS and BIM as well as between various programs that are used for building maintenance, building condition monitoring and document management. Typically, these programs have their own data structure and are not compatible with each other (Wang et al. 2013). The role of BIM for FM and BEMS within current practice is still unclear. However, as shown in Figures 5 and 6, there are possibilities for connecting BIM with various BEMS and other FM software. BIM would act as a central data repository that collects and stores data from various systems, and provide access to this data through a 3D, easy to use, user friendly interface.

5 CONCLUSIONS AND FUTURE RESEARCH

BIM implementation for facility energy management practices has gained increased interest both in academia and in industry in recent years. The current energy management practices have several drawbacks such as lacking automated data sharing, requiring manual data entry during O&M phase, and not facilitating continuous data flow throughout facility life cycle. BIM enabled energy management facilitates extracting and analyzing data for various needs to improve decision making process, which would translate into increased efficiency in work order executions and elimination of redundancy in data entry. Dynamic BIM models could improve documentation, minimize the cost of facility operations and maintenance, serve as a useful reference for future projects, and improve proactive maintenance planning which would lead to reduced energy consumption. Lack of guidelines to prepare BIM for BEMS, inaccuracy or incompleteness of as-built BIMs and interoperability issues between BEMS and BIM authoring tools are the main challenges that prevents from achieving dynamic BIM. In this paper, a conceptual framework that proposes to connect BIM with BEMS was introduced to help overcome the interoperability issue. The proposed conceptual framework will be implemented by developing a programming application to link BIM and BEMS and tested in future research. It is expected that it would help improve current facility energy management practice, and help save energy.

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References

Ahmed, M. F., Haas, C. T., & Haas, R. (2014). Automatic detection of cylindrical objects in built facilities. *Journal of Computing in Civil Engineering*,*28*(3).

Akanmu, A., Anumba, C., and Messner, J. (2013). "Scenarios for cyber-physical systems integration in construction." ITcon.

Akinci, B. (2015). Situational Awareness in Construction and Facility Management. *Frontiers of Engineering Management*, *1*(3), 283-289.

Azhar, S. (2011). "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry." *Leadership and Management in Engineering*, 11(3), 241-252.

Becerik-Gerber, B., Jazizadeh, F., Li, N., and Calis, G. (2011). "Application areas and data requirements for BIM-enabled facilities management." *Journal of construction engineering and management*, 138(3), 431-442.

Bosché, F., Guillemet, A., Turkan, Y., Haas, C. T., and Haas, R. (2013). "Tracking the built status of MEP works: Assessing the value of a Scan-vs-BIM system." *Journal of Computing in Civil Engineering*.

BIFM (2012) BIM and FM: Bridging the gap for success, [Online], Available: http://www.bifm.org.uk/bifm/filegrab/3bim-fm-report-bridgingthegapforsuccess.pdf (accessed 9-14)

Chen, J., Bulbul, T., Taylor, J. E., and Olgun, G. (2014). "A Case Study of Embedding Real-time Infrastructure Sensor Data to BIM." *Construction Research Congress 2014*, 269-278.
Claridge, D., Haberl, J., Liu, M., Houcek, J., and Athar, A. "Can You Achieve 150% of Predicted Retrofit Savings? Is it Time for Recommissioning?" *Proc., Proceedings of the 1994 ACEEE Summer Study*, 5.73-75.88.
Computer Integrated Construction Research Program. (2013). “BIM Planning Guide for FacilityOwners”. Version 2.0, June, The Pennsylvania State University, University Park, PA, USA. Available at http://bim.psu.edu.(accessed 9-14)
Doty, S., and Turner, W. C. (2009). *Energy management handbook*, The Fairmont Press, Inc.
Eastman, C., Teicholz, P., Sacks, R., and Liston, K. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*, John Wiley & Sons.
Fallon, K. K., and Palmer, M. E. (2007). "General Buildings Information Handover Guide." *Principles, Methodology and Case Studies (NISTIR 7417), August*.
Gallaher, M., O’Connor, A., Dettbarn Jr, J., and Gilday, L. (2004). "Cost analysis of inadequate interoperability in the US capital facilities industry, NIST Publication GCR 04-867."
Granderson, J., Piette, M., Rosenblum, B., Hu, L., and al, e. (2011). "Energy information handbook: Applications for energy-efficient building operations." *Lawrence Berkeley National Laboratory, LBNL-5272E*.
Herzog, P., and LaVine, L. "Identification and quantification of the impact of improper operation of midsize Minnesota office buildings on energy use: a seven building case study." *Proc., Proceedings of the ACEEE*, 3.121-123.129.
Hyvärinen, J., and Kärki, S. (1996). *Building optimization and fault diagnosis source book*, Technical Research Centre of Finland, VTT Building Technology.
Kelly, G., Serginson, M., Lockley, S., Dawood, N., Kassem, M. "BIM for Facility management: a review and a case study investigating the value and challenges." *Proc., 13th International Conference on Construction Applications of Virtual Reality*.
Laine, T., Hänninen, R., and Karola, A. "Benefits of BIM in the thermal performance management." *Proc., Proceedings of Building Simulation Conference, Beijing, 3-6 September*, Wiley.
Muthumanickam, A., Jain, R. K., Taylor, J. E., and Bulbul, T. (2014). "Development of a Novel BIM-Energy Use Ontology." *Construction Research Congress 2014 ©ASCE 2014*.
O’Sullivan, D., Keane, M., Kelliher, D., and Hitchcock, R. J. (2004). "Improving building operation by tracking performance metrics throughout the building lifecycle (BLC)." *Energy and buildings*, 36(11), 1075-1090.
Pietruschka, D., Biesinger, A., Trinkle, A., and Eicker, U. (2010). "Energy Efficient Operation of Existing Buildings Through Simulation Based Control Optimisation." *proceedings of IEECB 13-14 April 2010*.
Sadeghifam, A., Isikdag, U., Meynagh, M., and Marsono, A. k. "BIM application for energy optimization in a tropical public building." *Proc., 4th International graduate conference on Engineering, science and humanities IGCESH*, 573-578.
Salsbury, T., and Diamond, R. (2000). "Performance validation and energy analysis of HVAC systems using simulation." *Energy and Buildings*, 32(1), 5-17.
Son, H., Kim, C., & Kim, C. (2014). Fully automated as-built 3D pipeline extraction method from laser-scanned data based on curvature computation.*Journal of Computing in Civil Engineering*.
Teicholz, P. (2013). *BIM for Facility Managers*, John Wiley & Sons.
Underwood, J., and Isikdag, U. (2011). "Emerging technologies for BIM 2.0." *Construction Innovation: Information, Process, Management*, 11(3), 252-258.
Wang, Y., Wang, X., Wang, J., Yung, P., and Jun, G. (2013). "Engagement of facilities management in design stage through BIM: framework and a case study." *Advances in Civil Engineering*, 2013.
Yao, R. (2013). *Design and Management of Sustainable Built Environments*, Springer.
Yiu, C. Y. (2007). "Building depreciation and sustainable development." *Journal of Building Appraisal*, 3(2), 97-103.