Leadership in Sustainable Infrastructure
Leadership en Infrastructures Durables

Vancouver, Canada
May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

TRENDS, BENEFITS AND CHALLENGES IN UTILIZING BUILDING INFORMATION MODELING TECHNOLOGY FOR BUILDING OPERATION AND MAINTENANCE

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Abstract: This paper discusses the evolution of Building Information Modeling (BIM). BIM is a suite of technologies for representing buildings in semantic and geometric descriptions. It enables, through a variety of tools, various analyses of the underlying architectural, structural, mechanical, electrical and plumbing systems. An extensive literature review is carried out on current practices of utilizing BIM to design, construct and manage building operations through its expected lifecycle. The literature review starts by highlighting current practices and the benefits in using BIM technology. Subsequently, the paper addresses existing challenges in using BIM in assessing and understanding the operation and maintenance of buildings. Efforts made thus far to address these challenges are discussed. Our work shows that there is a substantial need for more holistic approaches to managing the lifecycle of buildings that considers not only interdependencies among core systems but also interdependencies with other interrelated civil infrastructure networks. These integrated holistic approaches will equip stakeholders of any building with mechanisms to secure a delicate balance between; 1) retained operational risks of building systems, 2) anticipated demands of their customers and 3) desired and competing objectives for both internal and external stakeholders. The paper concludes that current BIM practices pay negligible consideration to the interdependencies among building systems and components which can be a key in hindering effective implementation of sustainable operation and maintenance plans.

1 Introduction

Building Information Modeling (BIM) evolved over the last decade and became an essential component in tackling the inherent complexities in today's building projects. In building projects, there are many interactions between personnel from a wide-range of specializations in order to achieve a set of goals determined by a project sponsor. BIM is gaining momentum as a reliable technology for facilitating understanding, communication, collaboration and visualization of building projects (Kymell, 2013). BIM is used in a wide range of applications from automated site data collection to managing the lifecycle of existing buildings. However, BIM is utilized most extensively for addressing stakeholders' needs for design and construction processes. By examining the current state-of-the-art BIM technology, it is clear that there is less deployment of BIM technology for managing the complex aspects of existing building facilities. This paper starts by offering a discussion for current practices and uses of BIM in the building industry. The discussion also offers a close look at reported benefits and challenges for deploying BIM as a tool for buildings projects in general. The paper concludes with a proposal for an holistic approach to using BIM as a technology for managing the operation and maintenance of building projects.

2 Literature Review

The US National Building Information Model Standard Committee defines BIM as a digital representation of physical and functional characteristics of a facility (NIBS, 2015). Effectively, BIM is a shared knowledge resource about a facility, forming a reliable basis for decisions during its life cycle (i.e. earliest conception to demolition). Figure 1 shows the rise of BIM publications in two main phases for buildings in general, project management and facility management, from 2008 to 2017. These data were compiled from three online databases; Compendex, Inspec and GEOBASE. It is apparent that BIM is more prevalent when it comes to project management applications. On the other hand, BIM applications for facility management is increasing but not at the same rate as project management.

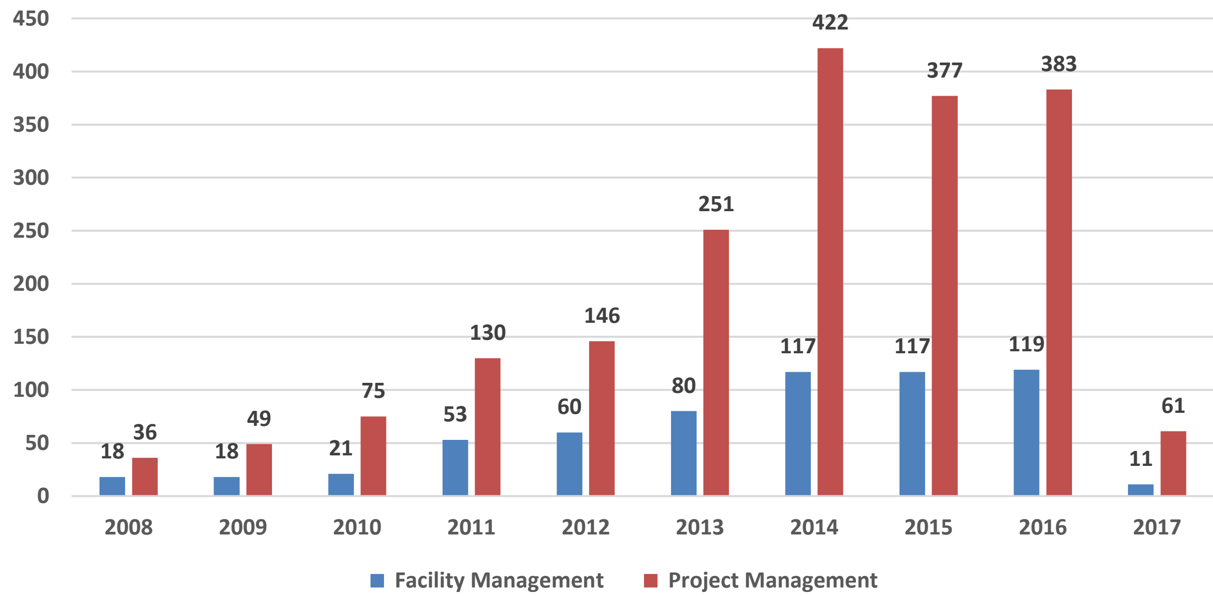

Figure 1 comparison between BIM publications in facility management and project management

Figures 2 and 3 show the top 10 domains where BIM is applied in project management and facility management fields. Buildings and high rise towers is the most dominant field for using BIM with 1006 publications for project management and 312 publications for facility management.

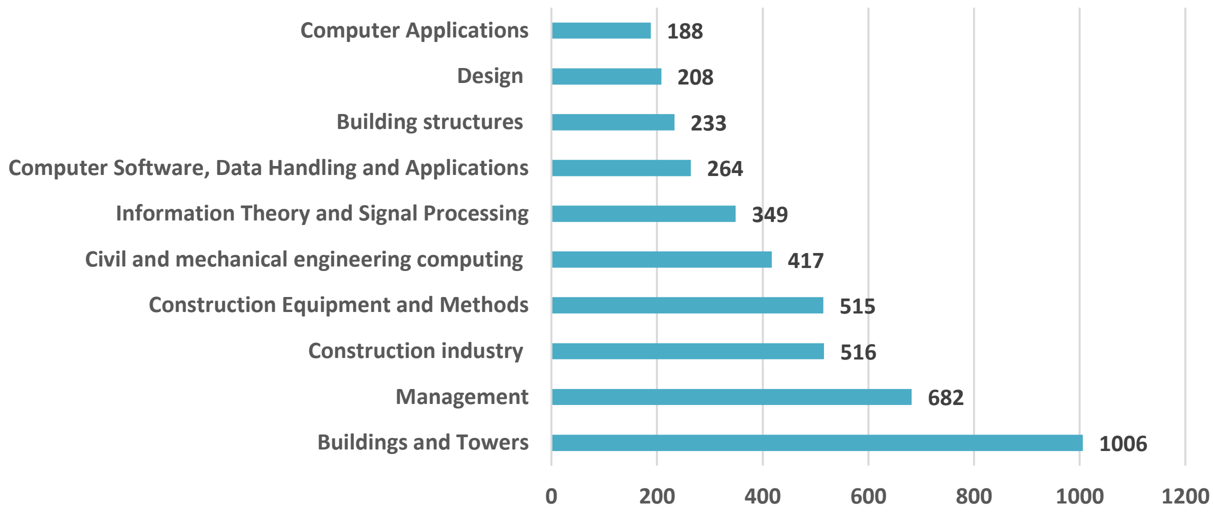

Figure 2 BIM applications in project management phase

These figures show also that BIM is utilized frequently in addressing topics related to public buildings during the facility management stage however BIM is more commonly used in dealing with management issues during the project management stage.

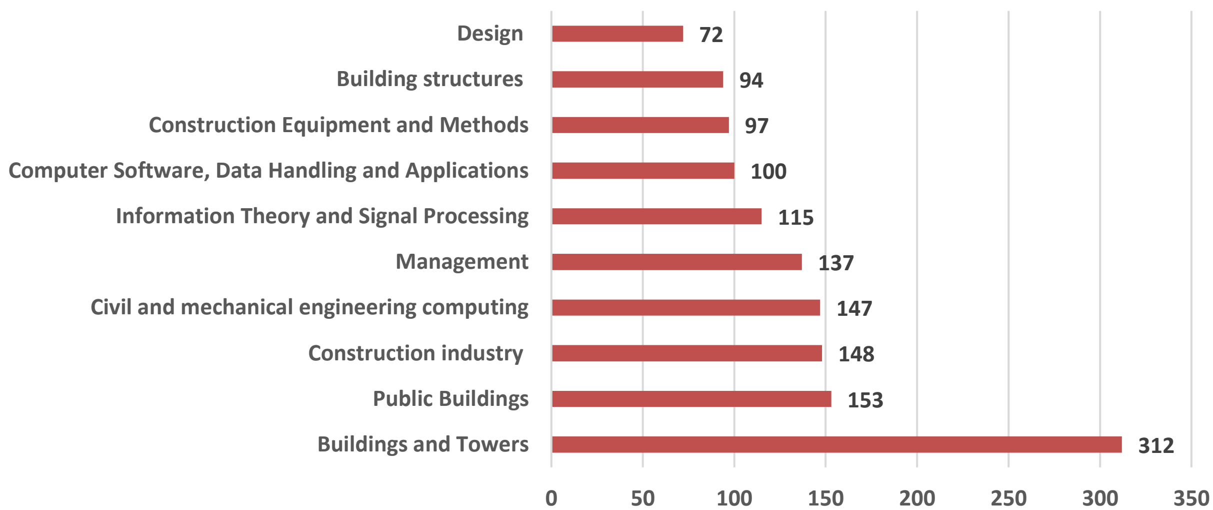

Figure 3 BIM applications in facility management phase

Based on Figures 1, 2 and 3, the literature review of BIM is divided into three sections according to its current dominant applications in the building industry; building design, building construction and building operation and maintenance management.

2.1 Building Design

BIM applications in the design stage emphasis on formulating design alternatives that realize the project scope. BIM provides an n-dimensional (n-D) environment for performing integrated design of architectural, structural and electrical, plumbing and mechanical systems. The n-D means a three dimensional model plus another dimension of particular interest to the stakeholder such as time, cost or quality. It is considered an improvement over traditional CAD platforms to enable more sophisticated analysis and design practices (Lee, 2006). Jalaei and Jrade developed an integrated building information modeling (BIM) and leadership in energy and environmental design (LEED) to evaluate design alternatives at the conceptual design stage of sustainable buildings. Lee et al. (2012) developed a Structural Building Information Modeling (S-BIM) to increase the efficiency of structural systems' selection and to obtain solutions that optimize constructability, structural safety, and economic feasibility of the building. Jiang and Leicht (2015) present an automated BIM rule-based approach to check the constructability of concrete formwork using building information modeling. Kim and Anderson (2011) extracted related energy information from a BIM model and simulate the energy behavior of any building in an energy simulation program (DOE-2) to forecast its energy consumption for a desired timeperiod. Hartmann et al. 2008 examined 26 case studies to understand how BIM models were used as visual representation tools for project planning and scheduling (Hartmann et al., 2008). Lee et al. (2014) enhanced BIM representation for data with an ontology-based approach to automate the cost estimation of building projects. Other BIM applications during the design stage include constructability analysis (Ganah et al. 2005), resource management (Akinci et al. 2003), coordination of mechanical, electrical, plumbing, and fire Protection (MEP/FP) systems on complex projects and (Khanzode et al., 2005, Staub-French and Fischer 2001). Some of the major benefits reported in the above mentioned research studies show BIM as:

1- BIM is providing a more holistic approach for evaluating design options considering multiple competing objectives. It allows owners and engineering consultants, for example, to pursue more sustainable and cost effective building designs (Kam-din and Qing, 2013).

2- BIM has improved the coordination and communication between owners, engineering consultants and contractors during the design stage. This has lead to time and cost savings during the design and construction stage because design efforts across multiple disciplines can be coordinated to achieve project goals and avoid potential conflicts (Onishi, Y, 2013).

3- Scope recognition is enriched during the design stage if contractors utilized the n-dimensional BIM models at the early stages of the project lifecycle (McCuen, T.L., 2015). BIM models are beneficial in understanding and preparing more accurate project plans, scheduling and cost estimation documents.

2.2 Building Construction

BIM applications in the construction stage focus primarily on time and cost reduction. For instance, BIM can be integrated with data collection technologies (e.g. sensors, tags, microcontrollers...etc.) to facilitate, for example, the tracking and controlling of material and human resources during construction. Moreover, BIM can be used with scanning technologies, automated object identification, to generate data on the actual progress of construction project activities (Ibrahim, 2015). Montaser (2013) presents a framework for tracking construction projects using a multitier system of BIM tools and data collection sensors. Soltani (2013) combines BIM with a localization algorithm to track resource locations during construction operations. Setayeshgar (2014) deploys BIM with dynamic virtual fences to identify potential accidents on construction sites for safety planning that reduces the risk of accidents. Jrade and Lessard (2015) adapt an integrated framework for tracking the time and cost of construction projects. Chau et al. (2004) proposed a four-dimensional (3D plus time) visualization of construction scheduling and site utilization to help construction managers plan day-to-day activities more efficiently. König et al. (2012) incorporate discrete event simulation with BIM to provide a more dynamic environment for scheduling construction projects to overcome the complex interrelationships among project's activities. In the above reported research work, the following are considered as major benefits for using BIM:

1- BIM has increased a project teams ability to track the progress of construction projects in real-time or near real-time. This helped project teams in achieving their operational goals during the construction phase by being equipped with more detailed daily progress reports from multiple sources simultaneously (Montaser and Moselhi, 2012).

2- Safety practices in construction sites has improved by utilizing BIM as a tool. Project staff have access to more advanced computational tools which are integrated with BIM to decrease the rate of fatal incidents due to construction equipment (Setayeshgar et al., 2013).

3- BIM has facilitated the process of identifying the best set of corrective actions needed to restore project performance when changes are required. BIM provides project managers with a set of simulation tools to experiment with the adjusted action plans in an n-dimensional BIM environment (Chau et al., 2004).

4- BIM has increased the efficiency of project documentation especially for complex and large projects. BIM allows stakeholders from multiple disciplines to update the documentation of projects using a traceable and authentic methodology (Park and Cai, 2017).

2.3 Building Operation and Maintenance Management

Engineers and operators started recently to deploy BIM for operation and maintenance applications. In facility management, researchers incorporated BIM to aid operators and engineers in tackling the following problems 1) locating assets, 2) data inoperability between BIM and external data sources used for operation and maintenance and 3) maintaining building systems operations during hazardous events. BIM is also used as a localization tool for as built three-dimensional (3D) BIM models and to display related operational data when needed (Krukowski and Arsenijevic, 2010). Amirebrahimi et al. (2016) provide a framework for data integration between BIM and GIS for flood damage assessment of buildings. Oti et al. (2016) offer a methodology for managing the operation and maintenance of buildings to meet energy standards and satisfy occupants' expectations. Wetzel and Thabet (2016) propose a BIM tool to address safety issues during hazardous events for buildings. In addition, operators and engineers maintain daily data about building systems and their basic components in external excel or database files. Hence, there is a need to manage the interoperability process between BIM data and external data sources to make better informed decision (Yu et al. 2000; and Shen et al. 2010). Asen (2012) integrates BIM with external operation and maintenance data sources to aggregate logical and spatial relationships between building components to find the cause-effect relationships. Despite many attempts to deploy BIM for operation and maintenance applications, they are still incapable of providing holistic solutions for complex buildings (López et al. 2016, Kassem et al., 2015; Volk et al., 2013). The major benefits of using BIM tools for operation and maintenance of buildings:

1- BIM is beneficial in eliminating delays, confusion, and inaccuracy generated by traditional O&M documents namely as built drawings, O&M manuals, maintenance schedules, room datasheets…etc. in either paper format or static digital formats such as excel or pdf files (Schevers et al., 2007).

2- Occupant satisfaction is improved as operators and engineers can combine sensors with BIM to tackle, in real time, operational problems as they arise (Inyim et al., 2014).

3- More reliable lifecycle management decisions can be implemented because BIM expedites the process for storing and analyzing condition and performance data for building elements in one platform (Charalambos et al., 2014).

4- BIM facilitates the process of forensic analysis by visualizing any potential failures when buildings are under malicious or natural hazardous events (Wan-Li et al., 2016). Stakeholders can experiment with various mitigation plans to minimize the vulnerability of existing buildings due to such hazards.

3 Recent Benefits and Trends in BIM

Research advancements in the use of BIM for design, construction and operation and maintenance provides a broad overview of how BIM can be used throughout the lifecycle of buildings. More recent research efforts, however, provide a quantitative summary from the building industry on the frequent uses of BIM in industry. Bryde et al. (2013) surveyed and examined 35 case studies reported in the literature in the period between 2008-2010. Their research shows BIM is used most frequently to address design and construction needs for new projects with a particular emphasis on cost and time control, communication management, quality assurance and scope definition. Barlish and Sullivan (2012) provide another analysis of the use of BIM that show most researchers are concerned with BIM capabilities in cost and time reduction and in improving the overall project management process for complex building projects. The responses Eadie et al. (2013) elicited from almost one hundred experts in the domain of BIM technology report that nearly half use BIM for architecture, structural and mechanical design of buildings and only 5% use BIM in facilities management. There is a tendency to incorporate BIM with external simulation models to generate exhaustive lists of design options during early stages of the buildings which can aid owners and consultants in exploring rich solution options more quickly. Also, BIM can be coupled with object recognition options to facilitate the documentation process for existing buildings which can help in transferring existing buildings data from a hardcopy format to digital format. This is possible because of recent advances in object recognition and imaging techniques for capturing the building and its systems and components. Augmenting BIM with virtual reality techniques is gaining momentum especially for construction and facilities management applications. Virtual reality techniques provide a rich experimental environment to compare existing designs to renovation alternatives.

4 Future Challenges for BIM Application in Existing Building

Volk et al. (2013) highlighted that despite recent advances for BIM in design and construction applications there is a substantially scarce use of BIM for existing buildings. First, there is difficulty in modeling or converting old as built records for buildings into digital records. Secondly, there is the problem of updating the information from multiple digital sources. Often, operators and engineers use a wide range of computational tools to handle basic daily operations. These tools are not necessarily compatible with current BIM platforms.

From the literature available, it also appears that the issue of inherent risk that results from the large web of interdependencies among building systems could benefit from more study. Building systems are located in an environment with operational dependencies among their most fundamental components. For example, a failure in an electrical system can cascade to mechanical, fire and plumbing systems. While this is fairly self-evident, these problems can cause costly down-time, or major barriers to recovery of operations in larger disasters when supporting infrastructure and operations beyond the building are also stressed. This raises the call for considering such interdependencies when planning the operation and maintenance of existing buildings and during early design stages. The following are suggested directions to facilitate BIM applications in operation and maintenance of existing building:

1- Convert as built data for existing buildings into digital format: recent years are witness to considerable advances in the conversion of as built drawings and other building data into digital format (Lu and Lee, 2017). When tackling the issue of transforming as built drawings of existing builds to BIM format, operators and engineers should balance between the complexity of their targeted buildings and expected costs for generating such digitized data. For example, as built drawings of small buildings are easier to digitize if scanned by high quality scanning devices. In absence of as built drawings, or for more complex buildings, image based techniques (e.g. LIDAR, Infrared, video images…etc.) are sufficient for generating as built data. The real concern will be the required time and cost needed to process, build and validate such models. Engineers are in need of guidelines or protocols to help them select the best approach to construct BIM models for existing buildings.

2- Tools to facilitate data interoperability between current BIM platforms and facility management software: more research effort is required to bridge the gap between current BIM and facility management platforms. This entails developing and implementing data interoperability frameworks that can handle data exchange between various formats (e.g. excel, database, HTML file…etc.)

and BIM platforms (e.g. OpenBIM, Revit, ArciCAD…etc.). The above stated research work provided generic frameworks but more testing and validation is required.

3- Optimize the lifecycle of existing buildings: BIM can be integrated with dynamic simulation and optimization environments to understand the complex interrelations among building systems. Current BIM platforms provide minimal capabilities for planning and managing the maintenance stage of existing buildings. These tools ignore interdependencies among building systems and hence do not provide a holistic approach to minimizing any external or internal risks throughout the lifecycle. Building systems are located in one environment and hence a failure in one system can have cascading effects on other neighbouring systems. For example, a failure in one HVAC duct may not only affect other interdependent ducts in the HVAC network but also users in the rooms and spaces covered by such system. This type of operational interdependency is not covered yet in the literature and more effort is need on optimizing building by considering such interdependencies.

5 Summary and Conclusion

This paper discussed how BIM progressed over time as a tool for the design, construction, operation and maintenance of buildings. The literature review examined current applications of BIM in buildings projects throughout the building lifecycle. The literature review also highlighted expected benefits of BIM technology in design, construction, operation and maintenance stages along with existing challenges.

The paper showed that current BIM practices pay little consideration to the interdependencies among building systems and components. This can be a key in hindering effective implementation of sustainable operation and maintenance plans. There is a significant need for more holistic approaches to managing the lifecycle of buildings that considers not only interdependencies among core systems but also interdependencies with other interrelated civil infrastructure networks. These integrated holistic approaches will equip stakeholders of any building with mechanisms to secure a delicate balance between conflicting and competing goals.

Acknowledgements

This research work was supported by Mitacs Foundation and RiskLogik through grant number [FR18211]. Also, The authors would like to thank Mr.Charles Chamberlain, Principal and COO at RiskLogik, for his support and assistance with this project.

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