A Case Study of Using BIM and COBie for Facility Management

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Abstract
This paper investigates the use of Building Information Modeling (BIM) and Construction Operations Building Information Exchange (COBie) for facility management on three projects where implementation concepts were used. Factors which affect these concepts are identified through a literature review. The study contains the following aspects of the implementation: responsibility for database formulation, characteristics of the database, technology, and effect on work order response times. A qualitative analysis was conducted to study the application of these concepts and to identify any problems encountered. Three case studies were conducted on projects where BIM and COBie were used for facility management. It was found that though the database generated by using these concepts is useful mainly for preventive maintenance, the data gathering and formulation process needs to be started earlier in the project. In order to make BIM more effective for facility management functions, such as space allocation, 3D mapping, building automation, etc., it would have been better to initiate BIM and COBie processes during early design and construction phases. The findings of this study can be used as a preliminary research upon which additional research on the implementation of BIM and COBie in facility management are further investigated and analyzed.

Keywords: Building Information Modeling, Case Studies, Databases, Information, Technology

Introduction

Building Information Modeling (BIM) is the process of generating and managing building data during its construction life cycle (Lee et al., 2006). BIM covers all the properties and qualities of building components, and can be used to depict the entire life cycle of the project encompassing construction and facility management. With documented impact in the design and construction, participants of the construction project are looking for ways to utilize benefits of BIM to improve the management and operation phases of facilities lifecycle (Jordani, 2010). However, the most important resource of the proper management of facility is the data or the information of the project. Without accurate as-built data, facility managers will not be able to function effectively (Kirkwood, 1995). There are numerous unrecorded information data points during the construction of a facility, which is not been transferred to the owner for management. The cause of this information loss is manual and paper based data-entry. One of the solutions for this situation is the use of BIM as database to store, organize and exchange information.

Due to fragmentation of the industry, the design, fabrication, and construction data produced by one group, like the general contractor, architect, or the facility manager, is usually created from scratch at every stage of the building life cycle, instead of being reused (Galleher et al., 2004). As oppose to AutoCAD files, which need to be corrected in all instants of the file, BIM auto updates the changes made in the design model and thus facilitates most recent information flow to the desired personnel. Buildings are complex today, and require high level information for its facility management. This information is vital and is required to be available in its most accurate form. The daunting challenges of facility management (FM) are revealed when the information exchange challenges experienced during design/construction is multiplied across the life cycle of a facility.

The concept of BIM is not new to the construction industry (Khemlani, 2003). BIM is a representation of a building as an integrated database of coordinated, internally consistent, and computable information in design and construction (Sabol, 2008). This integrated database can contain a vast amount of project information, like material quantities, installation dates, subcontractor responsibilities, type of material used in a facility, cost, schedule, etc. This means that a BIM model has great potential to simplify the data gathering and storing processes of a project since it can be used as a single source for all project data (GSA, 2011). The overall purpose of utilizing BIM for facility management is to leverage facility data through the facility life cycle to provide safe, healthy, effective and efficient work environments (Jordani, 2010). A vast amount of data is been generated during different phases of construction—the maintenance of this data may create greater efficiencies, such as having accurate as-built information to reduce the cost and time required for renovations, increasing customer satisfaction, and optimizing the operation and maintenance of our building systems to reduce energy usage.

This paper examines three projects where the concept of BIM for FM is being applied using COBie as the data handover tool. The effort is being undertaken by the university’s Health Science Center at two of its campuses, and by the University System at the Multi-Purpose Main Building of another campus. A common consultant was hired by the owner on all these projects. Since the accumulation of data for FM was started at different stages on these projects, it is interesting to study its effect on the efficiency of the data gathering process.

Literature Review

Technology in facility management

Information Technology (IT) and software are leading a revolution in FM targeting methods for data gathering and streamlining FM processes (Hinks, 1998). According to Lunn and Stephenson (2000), in the past 25 years, the power of IT systems and user availability has soared, although the cost has plummeted. Due to this, a synergistic interaction is now possible between the processes of FM and the specialist technology, wherein the networking and data handling capabilities of IT will directly affect FM processes. But there is a need to define how information systems contribute to the organization and how they are to be managed (Remenyi et al., 1997). The type of Information Technology and software procured for a facility also varies depending on the type and function of the facility (Mathiassen and Sorenson, 1996; Paulk et al., 1993). According to Hinks (1998), the emergence of a variety of specialist IT support tools for various FM activities appears to offer the scope for integration of FM function in those FM organizations which are ready and prepared to progress using it. Changes due to technology in facility management are inevitable, and organizations need to anticipate these changes and modify their strategies accordingly (Price and Shaw, 1998).

In the area of maintenance management, the literature identifies a need to fundamentally re-design the business processes in order to accommodate the computer rather than "the computer simply used to automate the traditional process" (Jones and Collis, 1996). Owen and Aitchinson (1988), stated that: "What organizations really want from IT is the information, not the technology." According to Remenyi et al. (1997), though information system outputs have automated FM processes like data entry of work orders in software systems and electronic logs, it has not succeeded in delivering significant savings in time and money to handle FM processes, such as work order management. This reflects the fact that information systems are not delivering adequate business benefits (Remenyi et al., 1997).

The growth in FM appears to replicate that which has occurred in construction; changes led by IT applications at an operational level rather than changes led by the evolution of the management process (Whitman, 1996). Tools such as computer-aided drafting technologies, 3D modeling technologies, and a host of internet and standards-based design and project collaboration technologies can streamline historically fragmented operations of FM in the capital facilities industry (Galleher et al., 2004). The latest in the advancement of the use of technology in FM is the use of web-based type software to access information in real-time through network communication. This started out by the use of simple network based activities like locating a person or an asset, submit a work order request, investigate health and safety data and display floor plans but now can support activities such as real-time design, workflow, collaborative single models, project management environments and facilities data repositories, which are of increasing tactical and strategic importance (Teicholz, 1997; Cairncross, 1998).

It is still difficult due to numerous reasons to find out which FM technology is beneficial for which FM activities. Even if technology is used on a large scale in FM, the right types of technology should be used at the right places to increase its effectiveness (Lai and Yik, 2012). As FM technology and automation becomes cheaper, the minimum size of the facility where it can be applied will also reduce. Advice on the considerations that should be taken in using a Computerized Maintenance Management Systems (CMMS) are available, but how such systems are being used to also evaluate facility performance and maintenance management performance is largely unknown (Levitt, 2007).

Interoperability problems in FM

Interoperability is defined as the ability to manage and communicate electronic product and project data between collaborating firms' and within individual companies' design, construction, maintenance, and business process systems (Galleher et al., 2004). According to the U.S. Census Bureau Report (2004), over $370 billion was invested in new facilities, facility renovations and additions in the United States in 2004. This figure excludes residential facilities, transportation infrastructure, such as bridges and roads, and facility operation and maintenance costs (Fallon and Palmer, 2006). The highest costs were incurred by owners and operators, and 85% of those costs were incurred during operations and maintenance. Annual interoperability costs of $15.8 billion were quantified for the capital facilities industry in 2002 (Galleher et al., 2004). The major cost was time spent finding and verifying facility and project information, which shows that extensive research is still needed to find out ways that can reduce the cost of operations and maintenance in building projects. As identified in Wong et al. (2005), there exist nowadays two main challenges in intelligent building integration research. The first refers to overcoming the hindering factors imposed by the lack of interoperability amongst the building automation systems products from the multitude of available vendors. The second challenge is on integrating building automation systems with the overall enterprise applications and moreover doing so over the internet (Pfeifer et al., 2001). Most of the problems in interoperability arise due to a lack of impetus to invest in interoperability solutions (Augenbroe, 2004).

A large number of documents and drawings are generated within the design stage of a construction project. The rapid growth in the volume of project information as the project progresses makes it increasingly difficult to find, organize, access and maintain the information required by project users (Ruikar et al., 2007). The need for integration of this information is evident due to the numerous benefits it can bring to both the occupants of the building as well as the facilities operators/managers (Wang and Xie, 2002). Hence strategic planning can be a way to avoid interoperability problems which helps in defining open and universal standards for not only current facilities, but for any planned facilities in the foreseeable future. Cotts (1999) distinguishes between long-term (more than 3 years) and short-term (0-3 years) planning in relation to FM, and it is primarily the long-term planning, which is strategic in nature, but it is important to take a coherent view on the different planning perspectives. Therefore, short-term planning has its main focus on existing facilities and the long-term planning is concerned with possible changes in the property portfolio. It is in this long term planning where BIM comes into the picture as a tool to be used for data handover (HNTB Federal, 2010).

Efforts to provide more effective and efficient solutions to the interoperability issues led to the adoption of open and standard communication protocols to uniform the communication process in all layers of interaction (Kastner et al., 2005). Since 1995 initiatives such as the Industry Foundation Classes (IFC) developed by the International Alliance for Interoperability (IAI) have driven interoperability between software vendors who support the sharing and reuse of design, as-built and maintenance data on building projects. According to Jordani (2010), well-run BIM projects result in coordinated and consistent information about a facility as it evolves through design and construction. This information in the form of a BIM model can by itself be used for operations and maintenance, without the need of the added step of data extraction.

Communication, co-ordination and partnering for FM

According to Oberlender (1993), once a project is completed and in use by the owner, a formal meeting should be held with owner’s representatives to obtain feedback regarding the performance of the finished facility. Such kind of communication is also important to gather the different parties to work together for the data formulation process during and after construction. Collaboration between all parties involved is now being seen as an important aspect to enable efficient FM even by the largest building owners in the US, like the General Services Administration (GSA 2011). According to Kubal (1994), partnering results in more successful business relationships and less dependence on legal assistance.

Some of the most effective information management tools in the building sector are project extranets, workflow management tools, and groupware applications for collaborative working

(Christiansson et al., 2002). It is important to understand that accurate equipment inventories affect many different aspects of building management, including management of energy, projects, operations, maintenance, and customer service, and, therefore, they affect the overall finances of an organization (Sullivan et al., 2010).

According to Kymell (2008) the use of BIM in construction and facility management is a great change and will result in a “cultural change” in every company that commits itself to its adoption. Kymell (2008) goes on to explain that this can have both a positive and a negative impact. Negative because any mistakes can be clearly seen, which can cause discomfort to project participants. According to Cholakis (2011), using project delivery systems which promote collaboration during construction will also help the facility throughout its lifecycle. By nature, when Integrated Project Delivery (IPD) and Job Order Contracting (JOC) work in done parallel with BIM, they enable the effective and transparent transfer of information among all construction project participants; this creates and builds trust and collaboration. For example, contractors provide input about the potential cost, constructability, and value engineering that aids the owners and design team to make more efficient and cost-effective decisions. In addition, the many challenges endemic to traditional construction delivery methods, such as miscommunications, change orders, adversarial relationships, and legal battles are virtually eliminated.

FM databases and Construction Operations Building Information Exchange (COBie)

Today’s buildings are increasingly sophisticated and the need for information to operate and maintain them is vital (Jordani, 2010). This information may also help track facility components accurately, identify inefficiencies in building operations, and respond quickly to client requests (Forns-Samso, 2010). Each facility component or asset has a cost associated with its installation, replacement, and scheduled maintenance. An accurate equipment inventory is essential for budgeting repair/replacement and maintenance costs (GSA, 2011). Typically, a facility manager obtains the majority of initial facility information from the general contractor constructing the facility. This process takes place at the stage just before the building is occupied, which is believed to be the best period to collect and streamline facility information (Edgar, 2000).

Facility management activities depend on the accuracy and accessibility of facility data created in the facilities’ design and construction phases and maintained throughout the operations and maintenance phase. Lack of this information can result in cost overruns, inefficient building operations, and untimely resolution of client requests (GSA, 2011). Operations and maintenance incurs additional time, manpower, and costs with inaccurate or lack of equipment inventories. The failure to properly track equipment inventories reduces the reliability of project scopes and cost estimates, impairs emergency response, and degrades the ability to make executive decisions (Keady, 2009).

Since the majority of the building data is generated during the construction phase, it is important to have an extensive database collection process throughout the life cycle of the project, starting from the design phase. Thus, if BIM has to be used as a “Portal to life cycle FM”, the timing of data gathering process early in the life cycle of the project is also important (Jordani, 2010). According to East (2011), most contracts require the handover of this data in the form of paper documents containing equipment lists, product data sheets, warranties, spare part lists, preventive maintenance schedules, and other information. Clayton et al. (1998) coin a new term called "operational documents" for this type of information, which are intended to reuse design and construction information to support operations and maintenance. Gathering this information at the end of the job, which is today's standard practice, is expensive, since most of the information has to be recreated from information created earlier on. Construction Operations Building Information Exchange (COBie) simplifies the work required to capture and record project handover data (East, 2011). The GSA BIM Guide for Facility Management (2011) defines COBie as a vendor neutral, IFC-based data exchange specification that describes the information exchange between the construction and operations phases of a project.

Many organizations have yet realized the importance of having a complete and formidable inventory of its facility to aid facility management (Sullivan et al., 2010). While it would seem obvious that a complete inventory would be the most beneficial to an organization, the reality is that most organizations do not understand the impact equipment inventories have on their business.

Research Methods

According to Yin (1994), case study research is the appropriate type of research to be used when the research questions are 'How' and 'Why' type of questions, and where no control over behavioral events is possible or desired along with a focus on contemporary issues to get the most realistic data and results. Contemporary issues, such as database formulation from BIM and other documents, use of COBie to format the data, and integration with the computerized maintenance management system, are the focus of this study. The purpose of this paper is to study three projects (as case studies) where the concept of BIM for facility management is being applied using COBie as the data handover tool.

Data collection

Two methods of observation were used for the case studies. They are as follows:

1. Documents – checking the accuracy of database and identification of problems was conducted through a three staged process: (i) Comparing the BIM to the as-built drawings of the project to ascertain the completeness of the model; (ii) Checking the COBie database for missing data by going through the spreadsheet to identify any missing cells; and (iii) Checking compatibility of the CMMS used on the projects with the COBie database and level of integration between BIM and the CMMS.
2. Interviews – held with personnel from the database formulation consultant company who was responsible for formulating the COBie database using BIM and other forms of inventory information in all the concerned projects. Interviews were also held with the facility managers of the concerned buildings. Questions about time saved in operation, compatibility issues in using BIM, and accuracy of the database were asked.

Limitations and delimitations

Following are the limitations and delimitations of the study:

- The results obtained are limited to the concerned projects.
- Methods of data collection used were documents and interviews. Hence no statistical tests were conducted on the data to arrive at a conclusion. The case studies undertake a descriptive approach and the pattern-matching logic to generalize results, where possible. This logic

compares a predicted pattern of results to be obtained to the actual results. If the patterns coincide, the results can help a case study strengthen its internal validity.
- Projects geographically close to the university in which the authors operate and within the same state were considered, because it was unfeasible for the researcher to travel out of state.
- The research was concerned with the process used for database formulation and the effects of BIM and COBie on the work order management system of the case study projects only.

Case Study Selection

The case studies selected are projects where BIM has been used for formulating a database to be used for facility management using COBie as a tool for database formulation. This data is related to floor, space, type, component, system, and document information of the facility in COBie or other data handover formats.

Reasons for choosing a multiple-case study approach:
- Multiple sources of evidence are available, in a manner encouraging convergent lines of enquiry so that the study is robust and compelling evidences can be found as to support or disprove whether BIM and COBie did help FM in the concerned projects.
- Although results of a case study research cannot be generalized to a broader theory because of the small sample size, having multiple evidence can generate future research on the subject.

Projects under-taken for case studies:

CASE I: University, Main Building

Owner: University System

Construction cost: $30 Million

Area: 90,300 GSF

The building houses classrooms, the university library, a multipurpose science laboratory, a dining facility, a bookstore, and administrative and faculty office spaces. Special considerations for design and construction:
- Built to LEED silver standards.
- Water conserving plumbing fixtures utilized throughout.
- State of the art lighting control systems incorporating occupancy sensors for energy conservation.
- Water efficient xeriscaping features a rich mix of native trees and plant materials that require little water and highlight the natural beauty of the region in which the project was built.
- The irrigation system utilizes cistern-based collection and rain water/HVAC condensation storage (2 - 25,000 gallon cisterns).
- West-facing windows incorporate use of sunshades made from cut aluminum panels reminiscent of the “hojalata” pressed metal craft that is native to the region in which the project was built.

Special considerations for FM: due to the varied types of spaces and high number of occupants, the facility management of this building is especially challenging:
- It requires co-ordination of the high volume of student and faculty traffic with the maintenance activities.

- Due to the special architectural features like windows with special aluminum sunshade panels, and decorative brickwork, special care and maintenance will be needed.
- Unique features such as xeriscaping and irrigation system utilizing cistern based collection from rain water/HVAC condensation will require advanced preventive maintenance.

CASE II: Health Science Center A
Owner: Health Science Center
Construction cost: $106 Million
Area: 280,000 GSF
The project consists of medical research and education building, the Health Professions Education Building, the Clinical Building and the central utility plant. The buildings house the College of Medicine, College of Nursing, Health Science Center Office of Information and Technology, Health Science Center Student Affairs, Learning Resource Unit, and a Clinical Learning Resource Center. Special considerations for design and construction:

- Concrete-framed structures with an exterior of clay masonry units and cut stone masonry veneer with glazed curtain wall and storefront system windows.
- Campus mechanical, electrical and plumbing design standards.

Special considerations for FM:

- Biological Safety Lab Level 3 (BSL 3) and vivarium which is applicable to clinical, diagnostic, teaching, research, or production facilities in which work is done with indigenous or exotic agents which may cause serious or potentially lethal disease after inhalation.
- All procedures involving the manipulation of infectious materials are conducted within biological safety cabinets, specially designed hoods, or other physical containment devices, or by personnel wearing appropriate personal protective clothing and equipment.
- In the vivarium, a portion of the ecosystem for a particular species is simulated on a smaller scale, with controls for environmental conditions.
- Some special provisions related to FM which need to be followed for BSL 3 labs and vivarium are:
  - The filtered exhaust air from the laboratory room is discharged to the outdoors.
  - The ventilation to the laboratory is balanced to provide directional airflow into the room.
  - Access to the laboratory is restricted when work is in progress.
  - The recommended standard microbiological practices, special practices, and safety equipment for Biosafety Level 3 is used and maintained.

CASE III: Health Science Center B
Owner: Health Science Center
Construction cost: $55 Million
Area: 130,000 GSF

The building houses the School of Medicine and the School of Nursing in the South Tower and Clinical and Office spaces in the North Tower, which are accessible to the public, along with seven clinics that serve as many as 700 patients per day. The technology-rich educational and clinical spaces include distance learning labs and networked lecture halls that coexist with informal collaborative spaces. Special considerations for design and construction:

- Accelerated schedule.

- Complex design program with several different types of user groups.
- The building is designed to encourage 'chance encounters' between researchers, patients, students and doctors.
- The exterior skin consists of face brick, cast stone and limestone.

Special Considerations for FM:
Since this a facility geared towards community development through providing healthcare, the following points are important from the perspective of FM:

- Space allocation and management of departments, clinics, labs, classrooms, conference rooms and open spaces in the building.
- Managing the flow of traffic of people efficiently throughout the building.
- Knowing the locations and information of every piece of equipment in the building so that minimum disruption is caused to the activities taking place in the building due to maintenance.

The following information was collected from each case study:

- Responsibility of database formulation;
- Characteristics of database:
  - Open standards;
  - Technical knowledge/capabilities;
  - Usability;
  - Database formulation and technology; and
- Effect on work order response time.

Findings

The following paragraphs outline the major findings of this study in terms of responsibility of database formulation, characteristics of database (open standards, technical knowledge/capabilities, usability, database formulation and technology), and effect of work order response time.

Responsibility of database formulation

Though all three projects had defined the responsibilities of the consultant and the buildings facility management department, the GSA BIM for FM guide (2011) states that to make full use of the capability of BIM, the process needs to start early in the design or the construction phase. Since there was no defined long term planning during the design and construction of these projects to use open standards for data creation and sharing, a significant amount of the data had to be re-created by the consultant after the facility was turned over to the owner. This created inconsistencies and inaccuracies which had to be corrected by the maintenance personnel of the facility.

The purpose of utilizing BIM for facility management is to leverage facility data throughout the facility life cycle to provide safe, healthy, effective and efficient work environments for the building user. Facility data is created throughout the design and construction process which should be used and updated throughout the facility life cycle – small projects, operations, maintenance, and major renovations and alterations. The maintenance of this data may create greater efficiencies, such as having accurate as-built information to reduce the cost and time required for renovations, increasing customer satisfaction, and optimizing the operation and maintenance of building systems to reduce energy usage.

Characteristics of the database

Open standards

There are two phases in which open standards and interoperable file formats can be used in the process of using BIM through COBie for FM: (1) Use of the Industry Foundation Classes (IFC) for formatting various BIM models created during design and construction phase; and (2) Extracting the information from the IFC formatted BIM files into a COBie based Microsoft spreadsheet, which can be imported into the Computerized Maintenance Management System (CMMS).

All three projects were successful in the application of the second phase, but could not accomplish the first phase. This was because of the fact that both the architect and the contractors were not stakeholders in this process, and hence, had no contractual obligation to format their BIM models or other forms of data in a specified manner. Figure 1 shows the phases of a project where data formatting and sharing specifications should be followed. Out of the phases mentioned, all three projects started formulation of the COBie dataset just after the construction phase. Hence information collected during building programming and design, which is critical to the COBie database, could not be assembled.

Figure 1. Typical phases of a project

Technical knowledge/capabilities

Knowledge of BIM, open standards of data transfer and CMMS is important for implementing any concepts related to BIM for FM. This was the primary reason for hiring the database formulation consultant by the Facilities and Construction, Utilities, Safety and Security (FUSS) administration of the university's Health Science Center (case studies II and III) and the University System (case study I). Both the FUSS and Facilities Services did not have personnel with specific experience or knowledge in handling this effort so a consultant with expertise in handling such projects was required. These organizations had to ensure integration of the COBie database with the CMMS and also have the capability to make changes in the COBie data throughout the building life cycle, so that the data is usable even after major renovations or changes to the facility.

FUSS administration of the Health Science Center, the organization responsible for FM of all their campuses, dealt with this problem by hiring a professional with experience of integrating COBie databases with CMMS, and can handle updating the database throughout the building life cycle. But this did not help in avoiding the problem of inaccurate inventory data, since no correct procedure was laid beforehand for data testing, and the maintenance personnel having experience of making databases for preventive maintenance were not a part of the planning process.

Usability

The common goal of all the FM departments on the three projects was to formulate a database which would help in preventive maintenance of the equipment. After testing and correcting the database they were confident that it could be used for preventive maintenance. Due to the integration of the COBie data with the CMMS, preventive maintenance work orders can now be generated automatically on weekly, monthly or quarterly schedule.

A complete database generated from BIM and other construction and commissioning documents can be used for a variety of purposes in FM other than preventive maintenance. Following are some of the uses of BIM listed in the GSA BIM guide for FM (2011):

- Reduce time by eliminating additional trips to the same location to carry out unscheduled work orders by providing accurate field conditions and maintenance information before leaving the office.
- Reduce the operations and maintenance (O&M) contract costs from incomplete equipment inventories. An accurate equipment inventory can reduce O&M contracting costs from 3% to 6% by identifying and tracking facility equipment and facility square footage.
- Optimize building performance by comparing actual to predicted energy performance. BIM can provide access to design and commissioning data for reference.
- Reduce costs of re-documenting "as-built" conditions and field surveys for building renovation projects. Savings could occur from reduction in time to verify field conditions, change orders due to unforeseen conditions, reduction in destructive testing and repair costs to confirm existing conditions.
- Increase precision in existing condition information, which is used for accuracy of rent bill management, reduction in costs for audits and re-walks.

Database formulation and technology

The database formulation consultant followed the following steps for data formulation in coordination with the facility management departments on all three projects:

- Allow work order process to stabilize with CMMS/FM team implementation work sessions: this involves mapping the work order process flowchart suitable to the FM personnel and related to the CMMS used.
- Map COBie data fields and documents to work order flow where provision of digital data will reduce time (requirements determination): this involves using the work order process flowchart and defining the scope to be covered by the data by holding meetings with the FM department, in this case the FUSS and Facilities Director of other campus. Since preventive maintenance was the goal, Tier 2 data (Equipment information – ID, make, model, serial number, warranty information, maintenance instructions, etc.) was in the scope.
- Evaluate current COBie data provisions and create reconciliation list of any missing data fields and/or documents (requirements alignment): this involves testing data accuracy. For the Health Science Center A campus, the data was found to have some incorrect asset ID's and inadequate detail after the handing over of the data to the FM department. Correcting the accuracy and completing the dataset is now the job of the facilities personnel on that campus. This has been corrected at the Health Science Center B campus, and the facilities personnel on that campus are part of the testing phase of the project. The University, Main Building project is still in the data formulation phase. But since the Facilities Services does not have

personnel with specially designated for testing the COBie database, it might result in inaccuracies.

Starting the database formulation early during design and construction may result in:

- Avoiding re-creation of data by the consultant.
- Complete BIM in open standards such as IFC from which a COBie file can be extracted directly.
- Direct integration of the BIM with the CMMS, which can enable real-time inventory mapping within the interface of the CMMS.

Effect on Work Order Response Time

Through interviews with facility managers of the FUSS, activities in a typical work order process which will be affected by using a COBie database imported into a compatible CMMS were identified. These activities were: find O&M data, review O&M data, identify warranty information, visit equipment, retrieve additional data in the field, and return to shop. Hence in the opinion of the facility managers, time to find out details of the equipment related to the work order and finding the location of the equipment may be reduced by using a COBie database sources from BIM and other construction documents. According to these facility managers, the cumulative saving in time responding to a work order will average 11.6 minutes per work order, or 8.7% time saving. Though this study is not based on actual work order data, it gives an indication that facility managers are confident that using these concepts will be beneficial.

Conclusions

The concept of using BIM as a data source and COBie as a data format is fairly new to the facility management industry. BIM is a concept which was first introduced in design and construction, but may present long term advantages throughout the building life cycle. Though the effort undertaken to utilize these concepts at the three projects studied is unique, the scope of using these technologies was limited due to the lack of long term planning during design and construction and inadequate knowledge of using these techniques. Major recommendations include:

- A significant amount of the data that had to be re-created by the consultant after the facility was turned over to the owner, which created inconsistencies and inaccuracies which had to be corrected by the maintenance personnel of the facility. Our recommendation would, therefore, be to implement an organization wide framework for contracts which the owner has with the architect, general contractor, subcontractors, and other stakeholders in a construction project which includes clauses for data sharing between the owner and any consultant hired by the owner throughout the building life cycle.
- All three projects created COBie-based Microsoft spreadsheets after the completion of the construction phase, but could not accomplish the establishment of Industry Foundation Classes for formatting various BIM models during the design and construction phases. Our recommendation would, therefore, be to ensure that data is created in a standard and easily accessible formats, like IFC for BIM, pdf for drawings, Microsoft excel for inventory information, etc., at the right time and phases as a project goes.
- Similar to the steps followed in the three project, our recommendation would be to establish organization- or campus-wide data formulation processes, which have to be followed by all new construction projects taking place on the campus.

- There are two types of capabilities and knowledge facility personnel should have to efficiently apply BIM and COBie for FM: (1) Knowledge of the concepts of BIM and relevant standards and formats; and (2) Knowledge of inventory information, which is required to perform preventive maintenance, emergency work orders, renovations, etc. All three projects did not have personnel with specific experience or knowledge in handling this effort, which resulted in hiring a consultant having the appropriate expertise. Our recommendation would, therefore, be that FM departments should not only have personnel with this knowledge but also make them a part of the planning process in database formulation.
- Tier 2 data was the scope of implementation in the three projects, as preventive maintenance was the goal. Our recommendation would, therefore, be that for the most effective and efficient implementation of BIM, Tiers 1 through 3 information should be used. This includes spatial programs with accurate as-built geometry (Tier 1), equipment information, such as ID, make, model, serial number, warranty information, etc. (Tier 2), and BIM with energy analysis predictions (Tier 3).
- All three projects started formulation of the COBie dataset just after the construction phase, and therefore, information collected during building programming, design, and construction, which is critical to the COBie database, could not be assembled. Our recommendation would, therefore, be that all stakeholders of the project, including the architect, general contractor, subcontractors, etc., as well as the BIM/COBie data formulation consultant and the facilities personnel should be brought on board from the early design and construction phases. This will enable application of specifications and standards to create and transfer data. Instant data handover after construction is possible in interoperable formats by using this process.

Quantifiable data is required to perform research on savings in work order response times. Such research will validate the claim that using these concepts helps FM. This will be possible if a facility uses proper data formulation processes from the design phase up to building handover. It will also require that data such as response times and changes in inventory is stored through its CMMS. This will enable an adequate amount of quantifiable data available for statistical analysis.

This research proves that the use of Building Information Modeling for database formulation and Construction Operations Building Information Exchange as a tool for data formatting affected the facility management of the concerned projects in terms of gathering formidable inventory data for preventive maintenance. This is as an indication to owners that the data generated during the design and construction phases should be maintained and handed over to the facility management department in a BIM-format, or in agreed interoperable formats through COBie. This may increase the value of the data and also provide savings of time and money in the operations of the building throughout its life cycle.

The use of COBie as a data handover tool also proved to be beneficial. It served the purpose of storing data extracted from BIM, as well other sources. It was used along with the BIM model, to extract space information and integrating inventory information. This was of significant advantage to avoid interoperability problems and served as universal data repository.

The importance of starting the database formulation early in the design phase is also underlined in this study. Since this was not done on the concerned projects, the scope of using the generated data became limited. It could only be used for preventive maintenance and not for emergency work order, energy analysis, and space management.

References

Augenbroe, G. (2002). "Trends in building simulation", *Building and Environment*, 37(2002), 891-902.

Cairncross, F. (1998). *The Death of Distance-How the Communications Revolution Will Change Our Lives.* Orion Publishing Group, London.

Cholakis, P. (2011). *BIM for FM/BIMF*. http://www.4clicks.com/wp-content/uploads/2011/06/4Clicks.BIMforFM.v3.1.pdf, (accessed 5/13/12).

Christiansson, P., Dawood, N., and Svidt, K. (2002). "Virtual Buildings (VB) and Tools to Manage Construction Process Operations." *International Council for Research and Innovation in Building and Construction.Distributing Knowledge in Buildings: An Architects View,* CIB-W78 Conference, June 12, 2002, Aarhus, Denmark.

Clayton, M.J., Johnson, R.E., Song, Y. and Al-Qawasmi, J. (1998). "A Study of Information Content of As-built Drawing for USAA." Thesis, Texas A&M University, College Station, TX.

Cotts, D.G. (1999). *The Facility Management Handbook*, 2nd Ed., AMACOM, New York, NY.

East, W. (2011). "Construction Operations Building Information Exchange (COBie)." *Engineer Research and Development Center,* U.S. Army, Corps of Engineers.

Edgar, A. (2000). *Facility Data Commissioning*, Graphic Systems, Inc., Wichita, KS, www.graphicsystems.biz, (accessed 3/25/2012).

Fallon, K. and Palmer, M. (2006). "Capital Facilities Information Handover Guide, Part 1." *National Institute of Standards and Technology, Technology Administration, U.S. Department of Commerce.* NISTIR 7259.

Forns-Samso D.F. (2010). "Perceived value of building information modeling in facilities operations and maintenance." Thesis, The University of New Mexico, Albuquerque, New Mexico.

Gallaher, M., O'Connor, A., Dettbarn, Jr. J., and Gilday, L. (2004). "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry." *National Institute of Standards and Technology, Technology Administration, U.S. Department of Commerce.* NIST GCR 04-867.

General Services Administration (GSA). (2011). "GSA Building Information Modeling Guide Series: 08 – GSA BIM Guide for Facility Management." *Version 1 – December 2011*, U.S. General Services Administration, Public Buildings Service, Office of Design and Construction.

Hinks, J. (1998). "A conceptual model for the interrelationship between information technology and facilities management process capability." *Facilities*, 16(9/10), 233–245.

HNTB Federal. (2010). "GSA BIM-CMMS Integration Process: BIM Logical Data Model Technical Memorandum – Draft." *GS00P09CYD0289*, U.S General Services Administration.

Jones, K. and Collis, S. (1996). "Computerised maintenance management systems." *Property Management*, 14(4), 33-37.

Jordani, D.A (2010). “BIM and FM: The Portal to Lifecycle Facility Management.” *Journal of Building Information Modeling,* Spring 2011, 13-16.
Kastner W., Neugschwandtner G., Srucek S., and Newman H.M. (2005). "Communication systems for building automation and control." *Proceedings of the IEEE,* 93(6), 1178-1200.
Keady, R. (2009). “Financial Impact and Analysis of Equipment Inventories.” *Facilities Engineering Journal*, November-December 2009.
Khemlani, L. (2003). “The IFC Building Model: A Look Under the Hood.” *http://www.aecbytes.com/feature/IFCmodel.htm*, (accessed 8/13/12).
Kirkwood, J. (1995). “Network technology: potential applications within facilities management.” *Facilities*, 13(11), 8-12.
Kubal, M. T. (1994). *Engineered quality in construction.* McGraw-Hill, Inc., New York, NY.
Kymell, W. (2008). *Building information modeling: planning and managing construction projects with 4D CAD and simulations*. McGraw-Hill, New York, NY.
Lai, J.H.K. and Yik, F.W.H. (2012). “Hotel engineering facilities: A case study of maintenance performance.” *International Journal of Hospitality Management*, 31, 229-235.
Lee, G., Sacks R., and Eastman, C. M. (2006). “Specifying parametric building object behavior (BOB) for a building information modeling system.” *Automation in Construction,* 15(6), 758–776.
Levitt, J. (2007). “CMMS – 9 plus 50 questions.” *Asset Management & Maintenance Journal*, 20 (2), 8-13.
Lunn S.D. and Stephenson P. (2000). “The impact of tactical and strategic FM automation.” *Facilities,* 18, 312-323.
Mathiassen, L. and Sorenson, C. (1996). “The capability maturity model and CASE.” *Information Systems Journal*, 6(3), 195-208.
Oberlender, G. D. (1993). *Project management for engineering and construction.* McGraw-Hill, Inc., New York, NY.
Owen, M. and Aitchinson, D. (1988). *FM-The Alternative IT Revolution*. Oxford, UK.
Paulk, M. , Curtis B., and Chrissis M.B. (1993). *Capability Maturity Model for Software, Version 1.1 Tech Report*. Carnegie Mellon University, Pittsburgh, PA, CMU SEI 93, TR 24.
Pfeifer, T., Micklei, A., and Hartenthaler, H. (2001). “Internet-integrated building control: leaving the lab-robust, scalable and secure.” *Proceedings of the 26th IEEE Conference on LoCill Computer Networks (LCN)*, IEEE Press, New York, NY, 306-315.
Price, I. and Shaw, R. (1998). *Shifting the Patterns*. Management Books, Oxford, UK.
Remenyi, D., White, T., and Sherwood-Smith, M. (1997). “Information systems management: the need for a postmodern approach.” *International Journal of Information Management*, 17(6), 421-436.
Ruikar D., Anumba C.J., Duke A., Carillo P.M., and Bouchlaghem N. M. (2007). “Using the semantic web for project information management.” *Facilities*, 25(13/14), 507-524.
Sabol, L. (2008). “Building Information and Facility Management.” *IFMA World Workplace 2008*, October 16,2008. Dallas, Texas.
Sullivan, G.P., R. Pugh, A.P. Melendez, and W.D. Hunt. (2010). “Operations & Maintenance Best Practices: A Guide to Achieving Operational Efficiency.” *Release 3.0.* U.S. Department of Energy. Federal Energy Management Program, http://www1.eere.energy.gov/femp/pdfs/omguide_complete.pdf, (accessed 02/20/2012).

Teicholz, E. (1997). “Trends in FM Technology – The Emergence of the Internet.” *GIS & Facility Assessment Decision Support*, Graphic Systems Inc.
U.S. Census Bureau. (2004). “Annual Value of Construction Set in Place. Washington D.C.” *U.S. Census Bureau Report*, 2004.
Wang, S., Xie, J. (2002). “Integrating Building Management System and facilities management on the Internet.” *Automation in Construction*, 11(6), 707-715.
Whitman, M.E. (1996). “IT divergence in re-engineering support performance: expectations vs perceptions.” *Information and Management*, 30(15), 239-250.
Wong, J.K.W., Li, H., Wang, S.W. (2005). “Intelligent building research: a review.” *Automation in Construction*, 14, 143-159.