A CASE STUDY OF THE USE OF BIM AND CONSTRUCTION OPERATIONS BUILDING INFORMATION EXCHANGE (COBie) FOR FACILITY MANAGEMENT

A Thesis

by

SALIL PRAKASH JAWADEKAR

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2012

Major Subject: Construction Management

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Approved by:

Chair of Committee,	Sarel Lavy
Committee Members,	Zofia Rybkowski
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ABSTRACT

A Case Study of the Use of BIM and Construction Operations Building Information Exchange (COBie) for Facility Management.

(August 2012)

Salil Prakash Jawadekar, B.E Mumbai University

Chair of Advisory Committee: Dr. Sarel Lavy

This study investigates the use of Building Information Modeling (BIM) and COBie for Facility Management on three projects where these concepts were used. Factors which affect these concepts are identified through a literature review. The study is divided into the sections of Responsibility for database formulation, Characteristics of database, Technology and Effect on work order response times. A qualitative analysis is conducted to study the application of these concepts and identify any problems encountered. A case study is conducted on three projects where BIM and COBie were used for facility management. It is found that though the database generated by using these concepts is useful for preventive maintenance, the data gathering and formulation process needs to be started during the design and construction phase to make use of BIM for facility management functions like space allocation, 3D mapping, building automation etc. This study can be used as a reference for further research based on quantitative analysis of the factors studied in the case study.

DEDICATION

To my family, friends and guides

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NOMENCLATURE

2D	Two Dimensional
3D	Three Dimensional
AHU	Air Handling Unit
BIM	Building Information Modeling
BMS	Building Management System
bSa	buildingSMART alliance
CAD	Computerized Aided Design
CAFM	Computer-Aided Facility Management
CMMA	Computerized Maintenance Management System
COBie	Construction Operations Building Information Exchange
FM	Facility Management
FUSS	Facilities and Construction, Utilities, Safety and Security
GSA	General Services Administration
HNTB	Howard, Needles, Tammen & Bergendoff
IAI	International Alliance for Interoperability
ID	Identity
IFC	Industry Foundation Classes
IT	Information Technology
NIBS	National Institute of Building Sciences
O&M	Operations and Maintenance

ODC	Office of design and communication
PBS	Public Buildings Services
PM	Preventive Maintenance
RDBMS	Relational Database Management System
RICS	Royal Institute of Chartered Surveyors
SCM	Supply Chain Management
VR	Virtual Reality
WO	Work Order
XML	Extensible Markup Language

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1. INTRODUCTION

Building Information Modeling (BIM) is the process of generating and managing building data during its life cycle (Lee et al. 2006). It covers geometry, spatial relationships, light analysis, geographic information, quantities and properties of building components (for example manufacturers' details). BIM can be used to demonstrate the entire building life cycle, including the processes of construction and facility operation (Liu et al. 2009). According to Kirkwood (1995) the practice of facility management involves the co-ordination and effective use of a wide variety of resources, including people, accommodation, fixtures and equipment. With documented impact in design and construction, owners and facility managers are looking for ways to extend the benefits of Building Information Modeling (BIM) downstream to improve the management and operations phases of a facility's lifecycle (Jordani 2010). However, the facility manager's most important resource, which is needed before any of the others can be properly managed, is information. Without accurate, up-to-date information, facility managers would not be able to function effectively or efficiently (Kirkwood 1995). There is additional and valuable information generated throughout the design and construction process that goes unrecorded or is not passed unto the owner at project completion (Mendez 2006). This is due to the weaknesses of the manual and paper based procedures for facility management like an unnecessary amount of non-productive

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time spent on paperwork and data re-entry, lower asset reliability due to maintenance backlogs and lack of information at the point of performance, less than optimal decisions made due to lack of complete, accurate, and timely information, a lack of definite accountability of critical equipment and material, and difficulty to track compliance with government, environmental and safety regulations (McAndrew et al. 2005). One of the proposed solutions to avoid these problems is to use Building Information Models as databases to store, organize and exchange structured information. Their use has proven to be successful in the design and construction phase. However, the benefits have not transcended to the O&M phase. Reluctance to process change, lack of knowledge and lack of documented metrics has prevented owners from adopting BIM to support the O&M phase (Forns-Samso 2010).

A large amount of data is generated during the design and construction phases of the project. But unfortunately, there are a series of discontinuities in the transmission of building data that occur throughout the typical building process (Autodesk 2008). Facility Managers are continually faced with the challenge of improving and standardizing the quality of the information they have at their disposal, both to meet day-to-day operational needs as well as to provide organizational management and planning (Sabol 2008). According to Jordani (2010) facility managers are responsible for major corporate assets, often accounting for 35 to 50 percent on an organization's balance sheet. Hence they have to use the resources available at their disposal to the fullest.

Due to the 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 lifecycle instead of being reused (Galleher et al. 2004). Even after the creation of Computer Aided Design (CAD), content changes still have to be manually integrated into the drawing and related data. Any drawings or data linked to the CAD is also not updated automatically once the parent file is updated. So it does not simplify or improve the data creation process like BIM does (East 2007). According to RICS FM Assessment of Professional Competence, facilities management is the total management of all services that support the core business of an organization which includes its building. Today's buildings are increasingly sophisticated and the need for information to operate and maintain them is vital (Jordani 2010). The daunting challenges of FM are revealed when the information exchange challenges experienced during design/construction is multiplied across the lifecycle of a facility.

BIM is a concept which is currently accepted by the design/construction industry as a data creation and modification tool, but it can be successfully applied throughout the building lifecycle (Forns-Samso 2010). The concept of BIM itself is not new to the construction industry, as the three-dimensional capability of BIM has been a dream of the construction industry, and the technology is not new either (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, etc. This means that a BIM model has great potential to simplify the data gathering and storing process 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 lifecycle to provide safe, healthy, effective and efficient work environments (Jordani 2010). Facility data is created throughout the design and construction process. Serial builders like the GSA intend to use and update this data throughout the facility lifecycle – through Small Projects, Operations & Maintenance, and Major Renovations & Alterations. The maintenance of this data will create greater efficiencies such as: having accurate as-built information to reduce the cost & time required for renovations, increasing customer satisfaction, and optimizing the operation and maintenance of our building systems to reduce energy usage.

This paper studies projects where the concept of BIM for FM is being applied using COBie as the data handover tool. We will discuss COBie later in the literature review. The effort is being undertaken by the Texas A&M Health Science Center at their campuses in Bryan and Roundrock and by the Texas A&M System at their San Antonio Campus Multi-Purpose Main Building. 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 will be interesting to study its affects on the efficiency of the data gathering process.

2. LITERATURE REVIEW

2.1 Technology in Facility Management

Information Technology and Software's are leading a revolution in Facility Management 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 whilst the cost has plummeted. Due to this, a synergistic interaction is now possible between the processes of FM and the specialist information 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 (Matthiassen 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. General Business support IT such as word processing and communications technology alters the operations of the FM activities, but does not directly influence FM processes like work order management, asset management, etc. (Hinks 1998). There are many acronyms to the use of technology if FM, like CAFM which stands for computer aided facilities management, which is to use available technology for tactical and strategic business success (Lunn and Stephenson 2000).

"What organizations really want from IT is the information, not the technology" (Owen and Aitchinson 1988). 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).

There have been five distinct generations of FM automation. Initially computerized automation was used for design and construction in the early 1960s (Howard 1998) and for space and asset management as early as 1963 in the CRAFT (Computerized Relative Allocation of Facilities Technique) system by Armour and Buffa for the evaluation of layouts (Mitchell 1990). 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). 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 huge savings in time and money to handle FM processes like work order management. This reflects the fact that information systems are not delivering adequate business benefits (Remenyi et al 1997). Due to the continuous progress in technology, the number of functions which can be successfully automated in a computerized FM system had also grown and FM software vendors have found it difficult to cope up with the growth. Therefore the computerized FM tools need to be flexible, "a living system" (Rothchild 1992) which is adaptable to change and can grow and develop with the organization. The growth in FM appears to replicate that which has occurred in construction; change led by IT applications at an operational level rather than change 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). FM automation aids knowledge integrity and helps the development for knowing, learning and thinking within the organization (Weick 1979). Figure 1 below by Lunn and Stephenson (2000) shows ten factors which have stimulated the growth of FM automation and technology and will continue to affect it in the future. It lists down change mechanisms, information technology, global competition, facilities costs, churn rates, employee expectation, information demands, cost of mistakes, design and inventory and strategic resource as factors causing growth of FM automation.

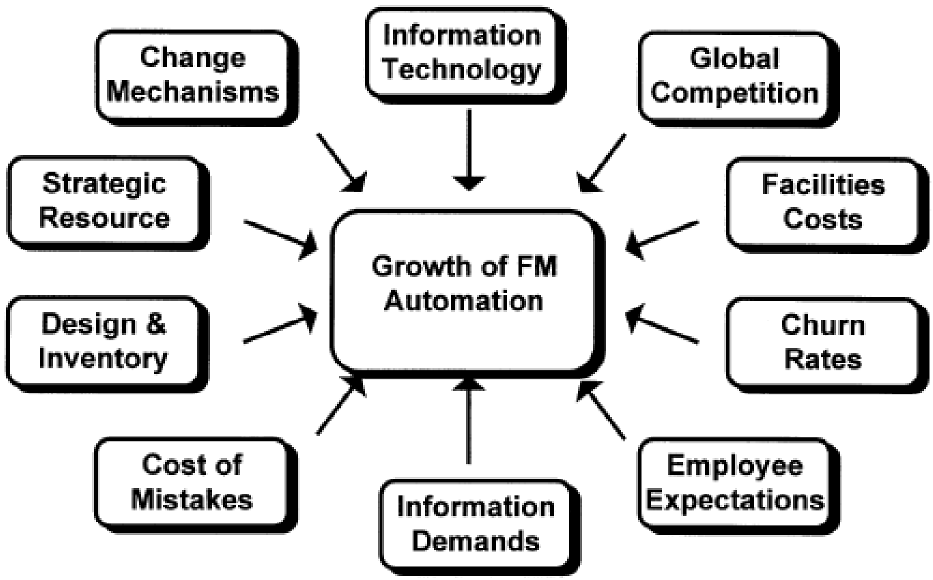


Figure 1 Factors affecting FM automation and technology (Lunn and Stephenson 2000).

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, right types of technology should be used at the right places to increase its effectiveness (Lai and Yik 2012). The need for the use of technology for FM will increase with the size of the facility (Teicholz 1992). Woznick (1996) suggested that "Facilities of 500,000 sq. ft or larger require a robust RDBMS (Relational Database Management System) and CAD system operating in a secure integrated network environment", whereas "Sites with less than 500,000 sq. ft may find the support costs to deploy a multiuser RDBMS unacceptable". 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 CMMS are available but how such systems are being used to also evaluate facility performance and maintenance management performance is largely unknown (Levitt 2007). Maintenance information, such as frequency of equipment faults, downtimes, repair costs, etc. is often regarded as too sensitive to disclose (Lai and Yik 2008) and empirical findings on maintenance performance are scarce. These are some of the reasons why today's computer aided facilities management (CAFM) is plagued by a lot of confusion, hype and unrealized objectives (Moulton 1999).

2.2 Interoperability Problems in Facility Management

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 2004b 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. $15.8 billion in annual interoperability costs 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. This study shows that extensive research is needed in finding out ways which can reduce cost of operations and maintenance in building projects. The notion of providing intelligence through interoperability in buildings' operations and enabling autonomic control and management of the corresponding field of facilities management has attracted significant research interest over the past decades (Snoonian 2005), yet reality has fallen well short of this vision (Braun 2007). 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 2002). According to Loesch and Theodori (2005) "Stories about documents locked in drawers or cabinets for years flourish and are now legendary". Many documents accumulate on desktops, collecting dust, and others reside on local computers with no global access to their data. Software licensing, obsolescence, and incompatibility and lack of organization are major problems. Crucial information is lost, misplaced or just hard to find. Organizational effectiveness suffers, and documents begin to lose their value as institutional assets. Inability to retrieve information is also a major problem, since information searching is mainly based on keywords search, which may retrieve irrelevant information due to term ambiguity and omit important relevant information when it is stored under different keywords (Ding et al. 2003).

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). People and knowledge are the most important strategic resources of an organization (Fruchter 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- and short-term 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. The short-term planning is related to less than three years, while the long-term planning horizon is more than three years. 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. The organizational placing of the strategic FM planning is according to Cotts (1999) a question which needs careful consideration except for small organizations, where the facilities manager himself can undertake the planning for the standards and formats required for the transfer of facility data. 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. Currently 38 vendors and developers have committed to the IAI initiative (Eaton and Lion 1999) which includes standards for the proposed development of interoperable object technology and virtual reality (VR). 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. Due to technology, facilities information will be available in the virtual domain making it truly interoperable and passed between real-time FM systems and distributed to FM users in a transparent manner (Randell et al. 1999). But Frost and Sullivan (2010) report that interoperability has not been completely achieved by providing data gateways and standard communication protocols. It becomes therefore necessary to develop new approaches to achieve integration of building automation systems and building services at a higher layer, e.g. middleware technologies (Wang et al. 2007, 2004; Ming et al. 2006) which combine building infrastructure and data communications (Maile et al. 2007).

Studying projects where technologies such as BIM are used for FM services will give an indication whether it can really help in reducing these costs (Brochner et al. 2011). BIM for facility management provides visualization, access to the precise location and relationships of building systems and equipment, and access to accurate existing condition attribute data, which can be compiled from different formats into a single BIM model. Building Information Modeling provides several advantages over traditional 2D drawings. It is a data-rich, object-based, intelligent and parametric digital representation of the facility (GSA 2011).

2.3 Communication, Co-ordination & Partnering for FM

According to Oberlender (1993), after a project is completed and in use by the owner, a formal meeting should be held with representatives from the owner's organization to obtain feedback regarding the performance of the finished facility. Courtesy of a more collaborative and informed commissioning process, the information captured in design/construct BIMs can be leveraged for downstream use by facility managers (Jordani 2010). This is an important activity for evaluating the quality of a completed project and assessing the satisfaction of the owner, because the true measure of the success of a project can be determined only by how well the finished facility meets the expectations of the owner. Such kind of communication is also important to gather the requisite parties to work together for the data formulation process during and after construction. The better the communication, the better are the chances of having a complete database of the project available for facility management. This lack of communication is also fostered by false impressions such as "inventory is a maintenance function" (Keady 2009). Because of these impressions, the majority of Chief Financial Officers (CFO) and Chief Executive Officers (CEO) are not provided the proper information to develop accurate budgets and make critical decisions related to their facilities. Currently, 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. For example, if an inventory is not accurate, an organization does not have the ability to reduce peak load during curtailment periods which increases the utility bill and, therefore, increases costs (Sullivan et al. 2010).

In manufacturing, the ability to produce a quality product largely depends on the relationship among the parties involved in the process. Similarly, close and long-term relationships between customers and suppliers in all the lifecycle phases of the building project are required if quality improvement is to be achieved (Dumas 1989). The operations phase of the lifecycle of a project hence is also benefitted through a better relationship among the parties, since a better relationship will result in healthier data sharing between the general contractor, architect, FM department etc. leading to the formation of a more complete database for facility management (GSA 2011).

According to Kubal (1994), partnering results in more successful business relationships and less dependence on legal assistance. Kubal (1994) also underlines that partnering has not and will not be successful with the contracts, contract methods, and contract clauses in use today. Relationships will typically involve fewer suppliers and mutual trust (Peters 1987). Partnering is, in fact, an attempt by industry leaders to move away from legal dependency and return to trust and open communications in the business relationships. BIM can play a major role in facilitating these partnerships, by facilitating communication and data sharing because participation of all involved parties like designers, contractors, fabricators etc. is required to make the model complete (Sawyer 2011).

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. He goes on to explain that this can have a positive as well as a negative impact. Negative because any mistakes can be clearly seen, which can cause discomfort to project participants. He recommends a strong and reliable team leader for the BIM effort related to the project, whether it be during construction or FM. 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 GSA (GSA 2011). As one of the largest building owners in the U.S. with a portfolio of buildings designed for 50+ years of use, GSA sees great benefits for developing and maintaining lifecycle data for their facilities. In 2003, the U.S. General Services Administration (GSA) Public Buildings Service (PBS) Office of Design and Construction (ODC) established the National 3D-4D-BIM Program. As part of this program, ODC has evaluated an array of 3D-4D-BIM applications on a number of capital projects.

According to Cholakis (2011) using project delivery systems which promote collaboration during construction will also help the facility throughout its lifecycle. By nature, when IPD and JOC work in 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 are virtually eliminated such as miscommunications, change orders, adversarial relationships, and legal battles. Co-partnering and Communication has also been fostered successfully through the use of concepts such as Supply Chain Management in the manufacturing industry (Vandaele and Gemmel 2007). Christopher (2005) defines SCM as “the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole”. In addition, Christopher (2005) defines the supply chain as “a network of connected and interdependent organizations mutually and cooperatively working together to control, manage and improve the flow of materials and information from suppliers to end-users”. Only a few studies have investigated SCM in the service industries such as facility management (Ellram et al. 2004; Mabert and Venkataramanan 1998). However, in services, SCM is becoming more and more important due to trends such as outsourcing (Li et al. 2006). As we will see in the case studies the activity to gather the data from the BIM models was outsourced and hence it will be interesting to study its effects. In addition, SCM in services deals rather with customer-supplier dyadic relationships than with the unidirectional movement of physical goods (Fitzsimmons and Fitzsimmons 2006; Sampson 2000). FM needs to be a support activity aiding the business of the organization (Nelson 2004). According to SCM (Christopher 2005) and FM theory (Williams 1999) the relationship between the internal support unit (FM department) and external providers (Architect, General Contractor etc.) should be managed by a professional procurer (consultant). How this relationship affected the cases will be studied later on.

2.4 FM Databases and COBie

Today's buildings are increasingly sophisticated and the need for information to operate and maintain them is vital (Jordani 2010). This information will also help to 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 the installation, replacement and/or scheduled maintenance for the component. An accurate equipment inventory is essential for budgeting repair/replacement and maintenance costs (GSA 2011). Maintaining large repositories of weakly structured information remains a tough and time-consuming task (Ding et al. 2003). A database system also should not become a "desert island data system" (Cooper 1997). It must form part of the organization's overall management and IT strategy, and have the flexibility to meet both current and future requirements. Craton and Robin

(2002) report that the convergence of Building Management System's (BMS) and IT is an emerging trend. If an accurate equipment inventory is not maintained, the number of man-hours needed to maintain and operate the facility cannot be easily calculated (Keady 2009). Typically, the 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). Also, personnel must be sent to the facility every time a project, contract, audit, or assessment of the facility is performed to capture the equipment inventory in order to accurately calculate man-hours. This method can easily create inaccurate costs in contracts, audits and projects, which, in turn, create contract modifications that increase the waste of manpower and staffing, and negatively impact the budget (Keady 2009). 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).

The primary information source for the construction phase is the information describing the facility created in the design phase. This has traditionally been transmitted via construction drawings and specifications. The construction contractor adds information about product sourcing, detailing, fabrication and assembly processes, and construction sequencing and schedule (Fallon and Palmer 2007). Since majority of the building data is generated during the construction phase, it is important to have an extensive database collection process throughout the lifecycle of the project, starting from the design phase. A case study conducted on a commercial facility by Broechner et. al. (2011) found that problems were encountered in the BIM model production stage because the process was started after the construction was complete and the facility was handed over. The model was planned to be used for relocation and facility management. The major problem was lack of access to adequate accurate input information to generate a minimal error high accuracy BIM model. Thus if BIM has to be use as a "Portal to lifecycle FM", the timing of data gathering process early in the lifecycle 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. This information is essential to support the operations, maintenance, and the management of the facility assets by the owner and/or property manager. Clayton et al. (1998) coins 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. COBie (Construction Operations Building Information

Exchange) simplifies the work required to capture and record project handover data (East 2011). Cholakis (2011) defines COBie as a specification for capturing design and construction information for facility managers and operators in a digital format. Other efforts in this area include Industry Foundations Classes and OmniClass™ which are data models, definition, rules, and/or protocols intended to define data sets and information pertaining to capital facilities throughout their lifecycles (GSA 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. Since different parties, using different kinds of software, all need to interact with COBie information, it can be displayed in several different formats. The standardized data architecture was developed to replace the current ad hoc process of leaving disparate piles of paper documents and digital files behind after a construction project is completed (Cholakis 2011). The IFC format for BIM can be directly used for COBie database integration or COBIE can also be used as a spreadsheet containing data from a BIM model (East 2007). Building product and process models have over time been implemented using a wide variety of knowledge representations such as relational databases, analogue representations (photos, video, hand drawn sketches), vector and bit mapped graphics, objects, rules and predicate logic in knowledge based expert systems, hypertext (mainly in web based environments), decision tables, etc. (Christiansson et al 2002). The building industry, unlike many other sectors, works on products and processes that are hard to formalize, and yielding models with overlapping information stored in large integrated models containing redundant information (East 2007). Thus it is important to have a consistent model and a format to gather data from different sources and compile it so that it can be directly used for data handover. BIM as a consistent model storing building information and COBie as a format to gather this data serve these purposes. These types of database technologies are intended to reduce management costs by creating a central and comprehensive resource of facilities information (Keller and Keller 2004).

But many organizations still haven't 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. This is not an uncommon reality in an environment where most facility managers are under the impression that a preventive maintenance inventory is more than sufficient to properly budget, operate and maintain a facility. Thomas-Mobley and Khuncumchoo (2006) report that of the information facility managers receive from construction managers during and after construction, warranty information, subcontractor/vendor contacts, maintenance information, training, drawings, submittals, product data/samples, regulation/legal issues, building systems, information, equipment information and material/finishing information, specifications, operation and maintenance information, contract information, and commissioning. Keady (2009) reports that instead of fixing a common problem in the industry of incomplete, inaccurate and self-generated equipment inventories, organizations will compensate by spending millions of dollars and thousands of man-hours. With increased global competition where the focus is on waste reduction and increased spending oversight, organizations can no longer afford to consistently waste time, manpower, and funds.

3. PROBLEM STATEMENT AND RESEARCH METHODS

The choosing of a research strategy is based on the following conditions:

- Type of research question.
- The extent of control an investigator has over actual behavioral events.
- The degree of focus on contemporary as opposed to historical events.

Yin (1994) gives an illustration of which research strategies can be used for different types of situations. In this concerned research the questions of 'How' will be answered and any control over behavioral events is neither possible nor desired. Control over behavioral events is specifically not desired because the process of using BIM and COBie for FM needs to be studied as is on the concerned projects, to get the most realistic data and results. 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 no control over behavioral events is possible or desired along with a focus on contemporary issues. Contemporary issues such as database formulation from BIM and other documents, use of COBie to format the data, integration with the computerized maintenance management sytem etc. will be studied in this research.

The questions addressed are as follows:

1. How does the use of COBie and BIM affect time required to close out a work order?

Any changes in time (variable) will be estimated by the processes eliminated or affected in the work order process flowchart by using BIM & COBie. The estimations will be based on opinions of the facility managers working on the building and work order data available for the building.

2. How does the work order handling process change by using COBie and BIM?

Flowcharts will be made of work order processes with and without the use of COBie and BIM. Broaddus & Associates (Program Manager) as well as facility managers of the concerned projects will be consulted in making these flowcharts which will provide a framework to estimate savings in time and cost in work-orders.

3. How does the data formulation process using COBie and BIM affect the personnel in the FM departments of the projects?

Interviews will be conducted with the program manager (Broaddus & Associates) as well as the facility managers and personnel of the respective buildings to find out whether any special technical know-how was required in creating and implementing BIM for FM and COBie related databases.

4. How does database formulation of inventory for preventive maintenance work using BIM and other construction documents as data sources and COBie as a data format?

A qualitative study of the database formulation process applied on the projects to formulate the COBie dataset will be studied. This will be compared to available literature about using the COBie format and conclusions and recommendations will be made.

3.1 Data Collection

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

1. Documents: This will included construction documents, design drawings, COBie files or building information models to use for FM if available. The purpose of this was ascertaining the accuracy of the database and also to identify problems in using these documents in their native format for FM as against BIM. Checking the accuracy 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. This was done through Interviews with database formulation consultant who is responsible for the implementation of BIM for FM as well as personnel in the facility management department of the projects.
   ii. Checking the COBie database for any missing data by going through the spreadsheet to find any missing cells. If there is any missing data, the reason for the same were found by checking compatibility issues between the database and the model, which can be use of different formats, using incorrect software, lack of technical know-how etc.
   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: Interviews were held with personnel from the database formulation consultant responsible for formulating the COBie database using BIM and other forms of inventory information in all the concerned projects as well as the

Facility Managers of the concerned buildings. Interviews were used to answer questions regarding time savings in work order management due to the use of BIM, compatibility issues in using BIM, accuracy of the database, technology used for the process, etc. The interviews did not have a standard set of common questions but were based on a typical set of questions, given in Appendix E, which were altered based on the Interviewee.

A copy of the IRB approval is in Appendix A. Typical questions asked during interviews are listed in Appendix B.

3.2 Case Study Selection

The cases to be selected are projects where BIM is being 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.

Please refer to the Appendix C for the framework to be used for data collection.

Proposed projects for case studies:

- Texas A&M Health Science Center / Bryan, TX
- Texas A&M Health Science Center / Round Rock, TX
- Texas A&M University / San Antonio, TX (Main Building)

Reasons for choosing a multiple-case study approach:

- Multiple sources of evidence are available, in a manner encouraging convergent lines of enquiry
    - By having multiple sources of evidence, the case study can be more robust or compelling since there were more than one source of data to prove or disprove whether BIM and COBie did help FM in the concerned projects.
- To enable the ability to generalize the results to a broader theory
    - Though results of a case study research cannot be generalized to a broader theory since they do not involve statistical testing with large sample sizes, having multiple sources of evidence through multiple cases can help in giving a direction to future research on the subject.

3.3 Limitations & Delimitations

3.3.1 Limitations

Following is a list of limitations of the case study:

- Since the research deals with the question of 'How' use of COBie and BIM affects Facility Management on a project, a case study approach is used for the research. Thus the results obtained are limited to the concerned projects.
- Methods of data collection used were documents and interviews. Hence no statistical tests are conducted on the data to arrive at a conclusion. The case studies undertake a descriptive approach and the pattern-matching logic to generalize results if 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. In this case if the patterns coincide, then use BIM for FM on the concerned projects is warranted; if they do not then the validity of using BIM for FM on these projects could not be found.

- Projects geographically close to Texas A&M University and also within the state of Texas were considered, because it was unfeasible for the researcher to travel out of Texas.

3.3.2 Delimitations

Following are the Delimitations for the case study:

- 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 a project only.
- As said above, data was based on documents related to the project and the interviews of the concerned professionals on the project. No real time data gathering of each work order generated on the project was done.

The database formulation process was studied by testing the completeness of the database for preventive maintenance, methods used to acquire the database and the technology used to gather the data. The responsibility of various activities involved in the process, as well as the level of communication and collaboration was studied. To gauge changes in work order handling time, typical flowcharts of a work order handling process (with and without the use of BIM) was distributed amongst the facility managers/program manager on the project and their opinions was recorded regarding savings in time (if any) for every activity on the flowchart through interviews. Since this method of using BIM for FM is in its infant stage, and the projects where it is being implemented are few, the researcher is of the opinion that the only credible sources of data are interviews of people involved in these projects and data obtained from the study of these projects.

4. CASE STUDY RESULTS

4.1 Introduction of Projects

4.1.1 Texas A&M University Main Building, San Antonio, TX

Figure 2 below shows the Main Building at Texas A&M, San Antonio.

(Photo Courtesy: Kell Munoz Architects)

Figure 2 Texas A&M University, San Antonio.

Owner: Texas A&M University System

General Contractor: Barlett-Cocke General Contractors

Architect: Kell Munoz Architects

Construction Cost: $30 Million

The Main Building at the Texas A&M San Antonio campus is a 90,300 gross square feet building housing Classrooms, the University Library, a Multipurpose Science Laboratory, a Dining Facility, a Bookstore and Administrative and Faculty Office spaces.

Special considerations for design/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 xeriscape landscaping features a rich mix of native trees and plant materials that require little water and highlight the natural beauty of south Texas. 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 south Texas. The design of these decorative panels draws from the imagery found on Mission San Jose in south San Antonio, use of "dark sky" friendly exterior light fixtures.

Special considerations for FM: Due to the varied types of spaces in the building and high number of occupants, the facility management of this building is especially challenging because:

- It requires co-ordination of the high volume of student and faculty traffic with the maintenance activities of the building.
- Due to the special architectural features mentioned above like windows with special aluminum sunshade panels, decorative brickwork and "dark sky" friendly exterior light fixtures, special care and maintenance will be needed.
- Unique features such as xeriscape landscaping and irrigation system utilizing cistern based collection from rain water/HVAC condensation will require advanced preventive maintenance.

- The building also has a Security Command Center to monitor access control and intrusion detection and has a 24 hr. video surveillance system.

4.1.2 Texas A&M Health Science Center, Bryan, TX

Figure 3 below shows the Texas A&M HSC at Bryan.

(Photo Courtesy: FKP Architects)

Figure 3 Texas A&M HSC, Bryan.

Owner: Texas A&M Health Science Center

General Contractor: Satterfield & Pontikes

Architect: FKP Architects

Construction Cost: $106 Million

Texas A&M Health Science Center in Bryan consists of the Medical Research and Education Building, the Health Professions Education Building, the Clinical Building and the Central Utility Plant. The total gross square footage is approximately 280,000 square feet which houses the College of Medicine, College of Nursing, HSC

Office of Information and Technology, HSC Student Affairs, Learning Resource Unit and a Clinical Learning Resource Center.

Special considerations for design/construction: Deemed a campus in a forest, the Texas A&M Health Science Center at Bryan portrays a progressive vision while honoring its natural environment. Buildings are concrete-framed structures with an exterior of clay masonry units and cut stone masonry veneer with glazed curtain wall and storefront system windows. The first phase of construction includes a central plant to provide thermal and electric utilities for the new buildings. The master plan also addresses the expansion of the central plant facilities as the campus grows, and the development of campus mechanical, electrical and plumbing design standards. The first phase of construction includes a central plant to provide thermal and electric utilities for the new buildings. The master plan will also address the expansion of the central plant facilities as the campus grows, and the development of campus mechanical, electrical and plumbing design standards.

Special considerations for FM: The facility contains a Biological Safety Lab Level 3 (BSL 3) and Vivarium. Biological Safety Level 3 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. A vivarium is an area, usually enclosed, for keeping and raising animals or plants for observation or research. Often, 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 vivariums 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.

Also the campus also has its own Utility Plant which increases the responsibility of inventory tracking and maintenance of equipment from the FM personnel.

4.1.3 Texas A&M Health Science Center, Round Rock, TX

Figure 4 below shows the Texas A&M HSC at Round Rock.

(Photo Courtesy: Thomas McConnell)

Figure 4 Texas A&M HSC, Round Rock.

Owner: Texas A&M Health Science Center

General Contractor: Chasco Construction

Architect: GSC Architects

Construction cost: $55 Million

The Texas A&M Health Science Center at Round Rock has a 130,000 gross square feet facility housing 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 7 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/construction: The accelerated schedule was the greatest challenge and a major success during this project. The design also met the challenge of a complex program and several dramatically different types of user groups. The building is designed to encourage 'chance encounters' between researchers, patients, students and doctors. The idea is to create links between spaces that encourage people to cross paths and thus create a sense of community. The public spaces like the rotunda with the 3 stories of communicating space and monumental stair is a physical connection of the different programs in the building and the architecture encourages people to interact with each other. 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, this can be aided by having real-time information about the status of every space in the facility.
- 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.

This building was designed to expansions in the future as well construction of more buildings on the campus. This updating the inventory information for this building through facility management regularly will help this campus grow in the future.

The Texas A&M Health Science Center at Bryan is the first campus to be using the BIM/COBie for FM process in the Texas Health Science Center. A Program Management firm was hired to plan and manage the data gathering process for this campus, which was subsequently extended to the Round Rock campus. Texas A&M University, San Antonio’s Main Building also has contracted the same consultant to make a complete dataset using available BIM models and existing inventory information. Many of the lessons learned from the Bryan campus were applied at Round

Rock, as observed in the case study, but still the final purpose of the FM departments on all three projects was to upload preventive maintenance schedules in the computerized maintenance management system (CMMS) used, and integrate it with the COBie database. Hence the database was not planned to be used for space allocation, emergency work orders, building automation etc. COBie data formulation was started at the San Antonio campus building after it had been operational for almost a year, so as-built data and inventory information was difficult to find in the proper formats and open standards. Since the major responsibility of the program manager was database formulation, they henceforth are called the 'database formulation consultant' in this case study. The case studies are divided in the following sections:

- Responsibility of database formulation
- Characteristics of database
    - Open standards
    - Technical knowledge/capabilities
    - Usability
    - Database formulation
- Technology
- Effect on Work Order response time

Some of these sections are described as common to all three projects since the same consultant and same methodology was used to gather data. These projects were selected because of their proximity to the researcher's place of study and because the

BIM/COBie data formulation process was started on them at different project stages. So it is interesting to study its affects on the process.

4.2 Responsibility of Database Formulation

Texas A&M HSC, Bryan: The database formulation consultant was responsible for gathering data. There was no requirement for architect or general contractor to format or provide the data in a predefined manner. Even in the planning stages with the consultant and the owner, the facilities co-coordinator and other maintenance personnel were not directly part of database accumulation and checking. Checking of the data involved matching equipment asset id's in the CMMS with asset id's in the COBie database and also verifying the accuracy of the specifications. The lack of involvement of the facilities coordinator and his maintenance staff in data checking led to an incomplete dataset delivered to the Facilities and Construction, Utilities, Safety and Security Administration (FUSS) of the Health Science Center. The database had incorrect asset id's and inadequate level of detail of inventory information. The maintenance personnel of the Health Science Center at Bryan had to reformat and correct missing and inaccurate information in the dataset which increased time and delayed the deployment of PM maintenance schedules which were planned to be loaded using the dataset. The original deployment of the database was delayed by approximately 3 months due to the inaccuracies in the data.

Texas A&M HSC, Round Rock: The database formulation consultant was also hired for the Round Rock campus of the HSC. After the inadequacy and incorrectness of the data obtained at the Bryan campus, the FUSS ensured active involvement of the maintenance personnel in the testing/checking phase of the database. The testing phase of the data involves coordination meetings between the database formulation consultant, the associate director of the FUSS and the Facilities Coordinator of the Round Rock campus. In these meetings, the facilities coordinator gives his input regarding any incorrect asset id's or incomplete information in the COBie database. These are incorporated in the database by the assistant director and the database consultant. This process also takes place through email, where the facilities coordinator inputs inventory information in a standard spreadsheet and sends it to the Assistant Director, who incorporates it into the database. This has resulted in a more complete and usable COBie database at the Round Rock campus. Figure 5 shows the relationships between the FUSS and the consultant. As seen in the figure below, the database formulation consultant is a third party consulting firm hired by the Texas Health Science Center, for their Bryan and Round Rock campus.

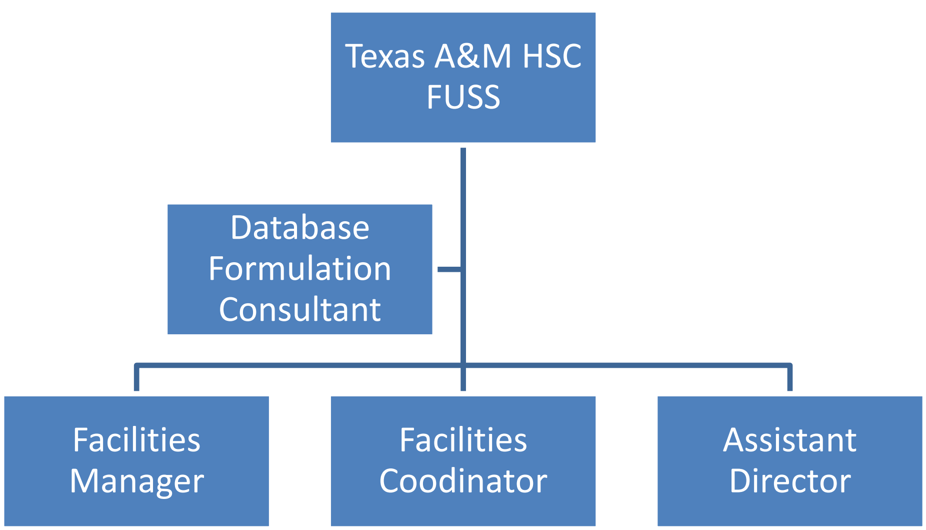


Figure 5 Responsibility flowchart, FUSS.

This consultant was in communication with the facilities manager and the assistant director of the FUSS regarding formulating the COBie database. The role of the assistant director was to help the consultant formulate the database and ensure integration of the database with the CMMS. The consultant was also in interaction with the facilities coordinator for checking the accuracy of the data.

Texas A&M San Antonio, Main Building: Though the San Antonio campus of Texas A&M University hired the same consultant, the owner and its involvement with the consultant on this project is different compared to the Health Science Center. The owner in this case is the Texas A&M University System. The Health Science Center specially hired an assistant director with experience in developing databases for the CMMS, who worked in conjunction with the consultant. Since the assistant director had previous experience of managing integration of facility databases with the CMMS, it ensured that the Health Science Center received a database which could be used with their CMMS. At the San Antonio Building, the facilities director is directly responsible for testing of the database and also its application. The same consultant team is creating the database for this project. As seen in Figure 6 below, on this project the facilities director takes up the responsibilities of both the facilities coordinator and assistant director of the Health Science Center, which means he has to check the data for completeness and accuracy as well ensure integration with the CMMS. He does have support of the building superintendent and the maintenance staff in checking the database. Texas A&M University, San Antonio has no plans of hiring a professional with a special skill set of integrating CMMS systems with databases. The facilities director does have experience of working with the CMMS used on the building. This project is still in the database formulation process, so it remains to be seen how successful they are in integrating the data received with the CMMS.

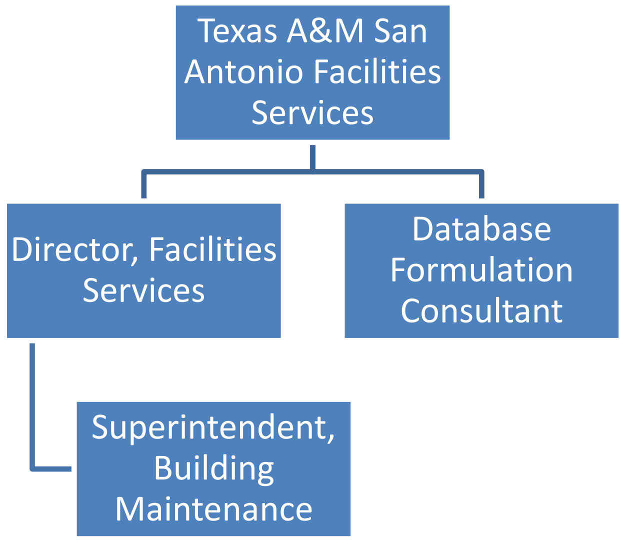


Figure 6 Responsibility flowchart, Facilities Services, Texas A&M, San Antonio.

4.3 Characteristics of the Database

4.3.1 Open Standards

The GSA BIM guide for FM lists three tiers of data requirements which can be met by using BIM. These are: Tier 1 - spatial program BIM, as-built geometry for equipment, Tier 2 - Equipment information like ID, Make, Model, Serial Number, warranty information, maintenance instructions, etc. and Tier 3 - as-designed BIM with energy analysis predictions. Out of these, the consultant mentioned that they expected to get only Tier 2 data from the BIM models and other data since the process was started when the construction was complete on all of the three projects. No processes were laid out in the construction phase nor the design phase for the designers, contractors and subcontractors to follow a process to neither format their data in open source standards nor collaborate with other parties involved. Hence, the consultant extracted only space allocation information from the general contractor's BIM. According to the consultant the space allocation data is 6-9% of the total inventory data set. This information was used to assign locations to inventory. Maintenance personnel along with the consultant had to conduct walkthroughs to gather other Tier 2 information like ID, Make, Model, Serial Number, warranty information, maintenance instructions which took added time and effort from the maintenance personnel. This caused a delay in the deployment of the COBie dataset.

Figure 7 below shows a flowchart of the generation, gathering and use of data and the formats and standards involved. The process phase and data format colored red were not used in any of the three projects. During the design and construction phase when data is generated, it wasn't recorded in a BIM file in an Industry Foundation Classes (IFC) format which is an open standard. An open standard is a standard that is publicly available and has various rights to use associated with it, and may also have various properties of how it was designed. Due to this, the data gathered later in the process wasn't completely sourced from BIM files. It had to be completed through facility walkthroughs by the consultant and took time which could have otherwise been avoided. The gathered data was assembled in a COBie file, which was directly accessible in the CMMS used on the projects. If the COBie data is not available for a project, the usual process is that maintenance personnel have to enter data gathered manually through walkthroughs, specifications, drawings etc. into the CMMS. A COBie file can be automatically uploaded into a CMMS and also recognized by most CMMS software packages. Hence regeneration or manual entry of data won't be required even if a new CMMS is deployed further in the building lifecycle.

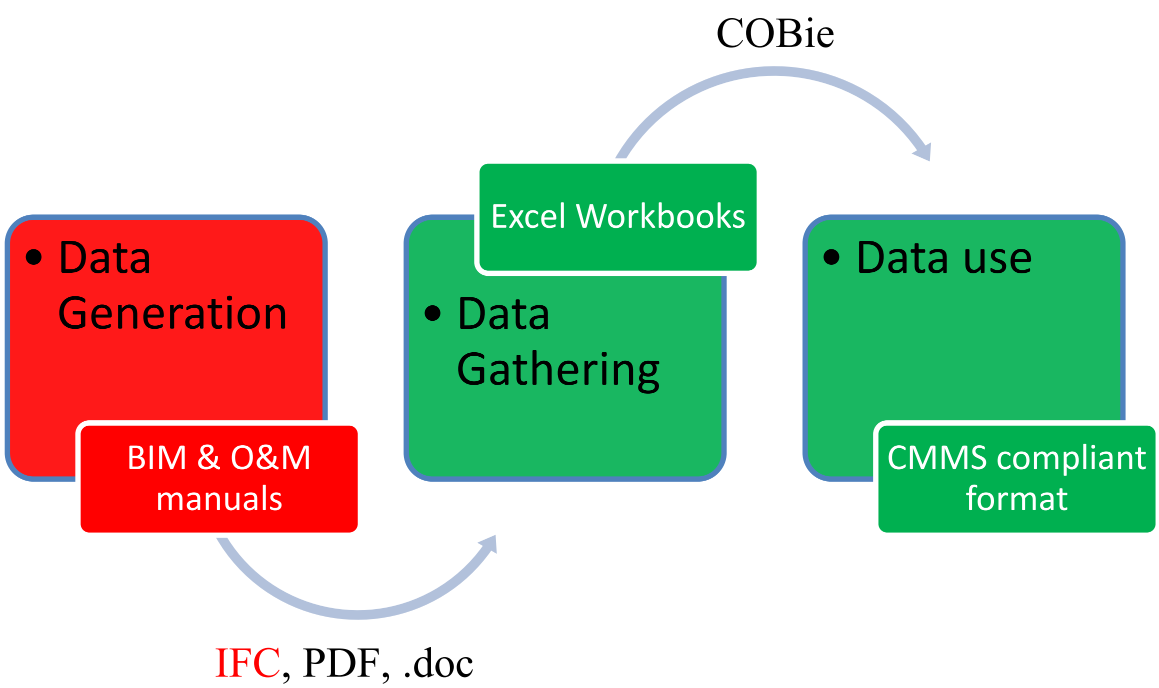


Figure 7 Open standards flowchart.

4.3.2 Technical Knowledge/Capabilities

One of the major problems with adopting a new technology is educating the users about its benefits and methods to use it (Forns-Samso 2010). This is one problem which has been effectively dealt with by the use of open standards like COBie for data formulation because:

- Since COBie is a Microsoft excel spreadsheet, it can be understood by most facility personnel as-is with a training sessions easily.

- All facility management personnel and offices had access to desktop personal computers (PC) which could open and edit spreadsheets. Hence available technology is sufficient for the use of COBie.

But the since data created at the Bryan campus had incorrect Asset ID's and inadequate detail level of data, the maintenance personnel had to come in and fix the inaccuracy in the data which wasn't anticipated before. This resulted in the added step of reformatting the COBie spreadsheet into separate spreadsheets having only those fields for which the data was required. For example, if a particular set of inventory had only its location field incomplete, the assistant director would send a spreadsheet having the asset (inventory) name and the facilities director would have to fill the location the next to it. This piece of data would be entered by the facilities director into the COBie spreadsheet and associate it with the rest of the Tier 2 data of the inventory. On the Round Rock campus the maintenance personnel are checking the data before taking delivery of the COBie data to avoid these problems. On the San Antonio building, the facilities director is performing the testing as well as involved with the consultant in formulating the data. He is required to have knowledge of formatting the COBie file as well checking if the data in the spreadsheet is correct.

Bryan and Round Rock, HSC: Dividing the responsibilities to accumulate and edit the database was effectively established by the Health Science Center at Round Rock and Bryan by:

- Creating a new position of the Assistant Director the in their organization. This professional had experience in database formulation for CMMS and had knowledge of the COBie format.
- Time which would have otherwise been required to educate existing personnel about using the system and the formats of the new type of database they received from the consultant was saved because the assistant director was given charge of handling data gathering, COBie formulation and CMMS integration. Hence no training to other personnel was required. Figure 5 shows how the cyclic process of data creation-use-gathering-reporting-editing took place.

As seen in Figure 8 below, the assistant director for FUSS was responsible for editing the data entered by the facilities personnel. This data was equipment specifications, preventive maintenance schedules and checklists. Equipment serial numbers, preventive maintenance schedules and manuals were submitted to the facilities coordinator by his staff. Though as mentioned earlier, the detail level of the BIM models was only limited to space allocation, other preventive maintenance inventory data like asset id's, make, model, serial number, warranty information, maintenance instructions etc. had to be accumulated through walkthroughs and equipment manuals. The Facilities Coordinator then entered this data in a simplified spreadsheet with fields only for the incorrect/inaccurate information. The data was checked, updated and submitted back to the Assistant Director who entered it into the COBie spreadsheet. This spreadsheet was then uploaded into the CMMS. The CMMS could populate the inventory information fields in its database from the COBie data.

Figure 8 Cyclic process of data creation.

Texas A&M San Antonio, Main Building: The facility management of the Main Building at Texas A&M San Antonio is performed by its building maintenance staff, headed by their Facilities Director. They have not hired a professional with experience handling CMMS integration with the COBie database like the Health Science Center. The Facilities Director is in direct communication with the consultant for testing the COBie database and also will be responsible uploading the data into their CMMS, which is TMA systems. Since the facilities director is responsible for both the data checking and integration with the CMMS, it reduces the number of levels of communication because:

- The database formulation consultant will work with the facilities director to format the COBie database.
- The maintenance staff will also be in communication with the facilities director to check and gather inventory data.

But it also may lead to inaccurate and incomplete data in the COBie file, since the facilities director does not have experience working with COBie and CMMS integration. The process is still in the database formulation phase of this project.

4.3.3 Usability

The inventory database integrated with the CMSS is planned to be merged with preventive maintenance schedules of the inventory. These schedules are obtained either from available equipment specifications or through RSMeans. None of the equipment specifications or details were available in the BIM models. They were usable only for space allocation.

The FUSS and the Facilities Services of Texas A&M University have managed to acquire equipment specifications and preventive maintenance schedules for all equipment in the building through following sources:

- Construction, commissioning documents of the equipment.
- Manufacturer's manuals of the equipment.
- Facility walkthroughs and noting down equipment type and serial number. This information was used along with RS Means.

The FUSS and the Facilities Services of Texas A&M San Antonio were fully satisfied about the capability of the dataset for preventive maintenance because:

- A complete COBie dataset will have all of the inventory information and asset id's matched correctly. This will enable identification of equipment in considerably less time compared to manually checking this information.
- Both CMMS used on the projects, AiM™ and TMA systems are COBie importable, which means that they can recognize data in the COBie format and automatically populate their data fields. This enables automatic generation of weekly and monthly preventive maintenance schedules through the CMMS interface.

Following are the reasons why preventive maintenance is important for the FUSS and Texas A&M San Antonio facilities services:

- Increasing the usable life of its inventory through its lifecycle.
- Reduced number of emergency work orders due to better maintenance of equipment through scheduled preventive maintenance.

Table 1 below from the database formulation consultant table shows the phases of the building lifecycle in which data gathering was undertaken and types of information captured. This table is applicable for all three projects. As seen from the table, no data accumulation was undertaken during the programming and design phases. The documents and information generated during these phases was not used. This was because the database formulation process was started after construction, when only construction documents were available. Installation and Commissioning documents from the Construction phase were the major sources of data.

Table 1 Data sources.

Project Phase	Contracting Phase	Information Captured	Case Study Scope
Requirement	Programming	Space Program	No
		Product Program	No
Design	Documents	Early Design	No
		Schematic Design	No
		Coordinated Design	No
		Design Reviews	No
	Specification	Product Specifications	No
		Product Discovery	No
Construction	Bidding	Bid Inquiries	No
	Selection	Preparation and Submittal Review	No
		Shop Drawings	No
	Installation	Installed Product	☑
		Inspect Products	☑
		Punch List	No
	Commissioning	Capture Warranty Data	☑
		Capture Maintenance Data	☑
		Capture Systems Data	☑
		Capture Commissioning Records	☑
Operations	Not Applicable	As-Built Data and Documents	☑
		Information to Support O&M Needs	☑

4.3.4 Database Formulation

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

- Allow WO (work order) process to stabilize with CMMS/FM team implementation work sessions: This involved mapping the WO (work order) process flowchart suitable to the FM personnel and related to the CMMS used.
- Map COBie data fields and documents to WO flow where provision of digital data will reduce time (requirements determination): This involved using the WO 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 the San Antonio 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 / documents (requirements alignment): This involved testing data accuracy. For the Bryan Health Science Center 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 Round Rock campus, and the facilities personnel on that campus are part of the testing phase of the project. Texas A&M San Antonio 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.

The GSA guide for using BIM for FM (2011) states that best results are obtained when the project management or database formulation consultant works with the design and construction and specifies:

- Data formats to be used like IFC for BIM, pdf for drawings, Microsoft excel for checklists etc. to avoid interoperability.
- Responsibilities written in the contracts with the architects, general contractor etc. for sharing and transferring data produced with each other as well as the owner.

Since the data formulation process was started after construction, data created during design and construction was not stored interoperable formats. There was no contractual binding on the architect, general contractor, sub-contractor etc. to share and transfer information.

Texas A&M Health Science Center, Bryan: On the Texas A&M Health Science Campus in Bryan the database formulation consultant was hired just before the construction of the project, but the data gathering process started after construction and building handover. The data created during the design and construction was not stored in open standards like COBie, Microsoft Excel spreadsheets or IFC, hence it needed to be recreated by the consultant through available construction documents and facility walkthroughs. No standards or rules of procedure were laid out which neither the architect nor any of the contractors had to follow to prepare and share their data. Figure 9 below shows how this process was completed. As seen from the figure, the data formulation process was performed independently by the consultant. There were no direct inputs from the facilities personnel like the facilities coordinator or any of his maintenance staff while the data was collected or during database handover .This communication gap between the consultant and the facilities personnel on the Bryan campus resulted in inaccuracies in the data.

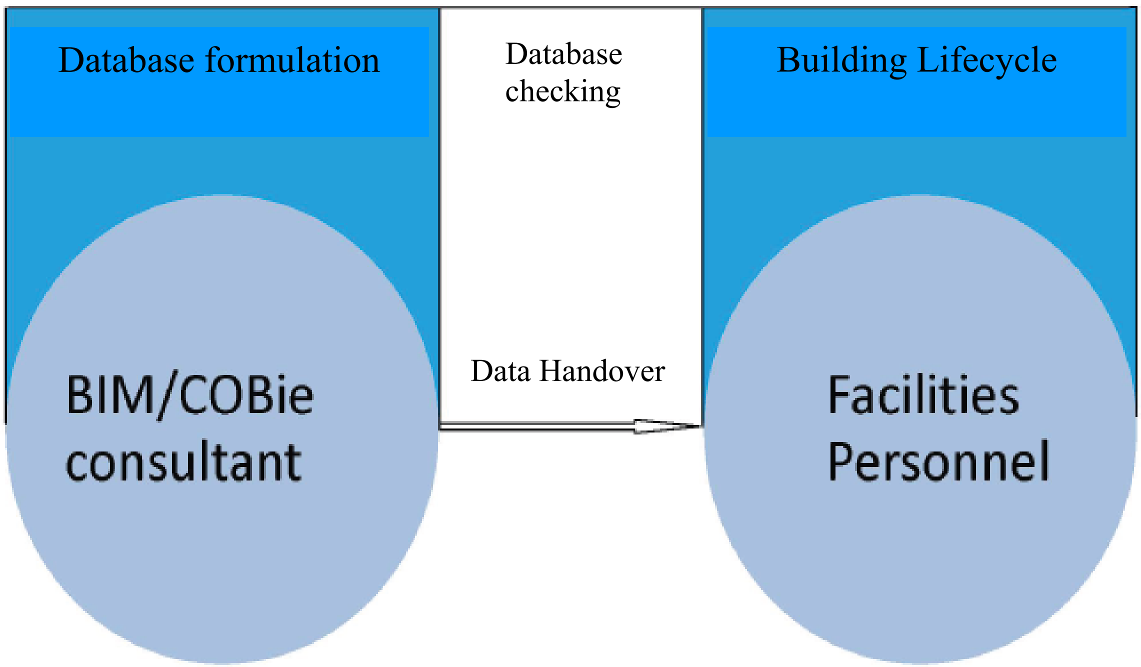


Figure 9 Database formulation, Bryan HSC.

The data was checked for accuracy and completeness after the final product was delivered to the maintenance staff on the Bryan campus. Following were the observed inaccuracies:

- **Asset Id's assigned to inventory:** Asset Id's are numerical identifiers for inventory and are used in most CMMS. Inventory was assigned incorrect Id's due to error or incorrect information.
- **Low level detail in the inventory dataset:** Since the intended use of the dataset was for preventive maintenance, a certain level of detail was required to differentiate types of equipment and then assign a PM schedule to each piece of inventory, for example all air handling units (AHU) were grouped under a single category and were not divided into different types of AHU's. The maintenance personnel had to discover various details and types of the equipment through walkthroughs, which has delayed the deployment of the data for use by three months.

Every time an inaccuracy was found, it had to be reported to the facilities coordinator, who made changes to the simplified spreadsheet he worked with. This spreadsheet was then submitted to the Assistant Director who made changes to the COBie database and CMMS. Every change had to go through multiple levels of communication before being submitted into the CMMS.

Texas A&M Health Science Center, Round Rock: At the Texas A&M Health Science Center, Round Rock the process was modified after the problems encountered at the Bryan campus. Figure 10 below describes the process followed for the Round Rock campus. Like the Bryan campus, the consultant was hired during the design and construction phase but there were no specifications laid out for the architect or the contractor to format and share their information. So the problems encountered here were same as the Bryan campus. But as seen in the figure below, during the data gathering and checking phase the facilities personnel were consulted and the process was undertaken in collaboration with the FUSS. This avoided the problems of incorrect Asset Id's and Low detail level in the inventory.

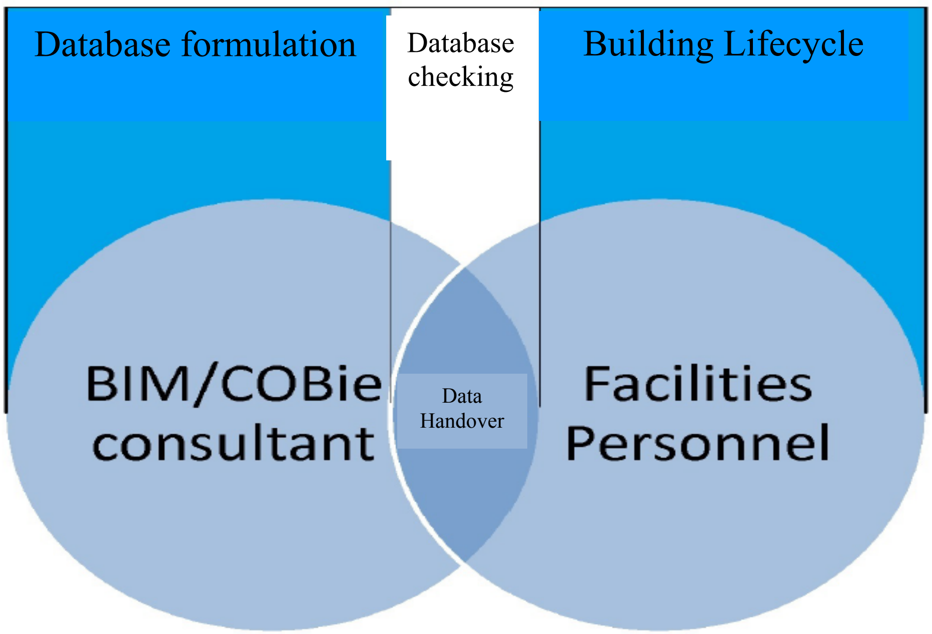


Figure 10 Database formulation, Round Rock HSC & Texas A&M, San Antonio.

Texas A&M University San Antonio, Main Building: The process of data formulation is the same as in the Round Rock campus. Data formulation and testing for completeness is being carried out in conjunction with the Facilities Director.

4.4 Technology

The technology in the form of software packages was the most important part of the database formulation process. This is because the use of the COBie spreadsheet for BIM can be made possible by using software packages capable of extracting data from a BIM or other sources of information like documents and drawings, and a CMMS system capable of recognizing a COBie spreadsheet. The database formation consultant used 'Onuma System' and 'EcoDomus' software packages, to gather and format the data in a COBie spreadsheet. This streamlined the data formulation process for the consultant by:

- Avoiding the confusion of using various data formats and transferring information from multiple spreadsheets manually into a COBie. Both software's could output a COBie file automatically with information entered into the software package.
- The COBie file generated by both software packages was compatible with both CMMS used on the projects.

The processes where the software packages were used are as follows:

- Gather data through available BIM models, facility walkthroughs, CAD drawings and maintenance personnel.
- Feed this data into the database repository of the software package used.
- Use the software package to populate the COBie compliant spreadsheet and deliver to the owner.

Figure 11 shows the interaction between the software packages used and the related sources of data. As seen in the figure, Onuma System and Ecodomus were used to formulate the COBie spreadsheet from the available sources of data, which included data from BIM models and inventory information gathered from facility walkthroughs. Since the consultant was the same on all three, the same technology was used for formulating the dataset on every project.

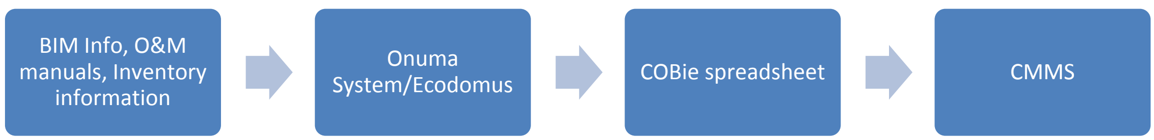


Figure 11 Technology flowchart.

4.4.1 Onuma System

Onuma System provides various modules geared for all phases of design, construction as well as facility management. Figure 12 below gives a list of its functions, and which the functions used for by the consultant for formulating the COBie database. The rectangles colored green show the path followed by the consultant using Onuma Systems to develop the database for all three projects. The BIM/COBie Excel Templates were set up to guide in the formatting of facility management data and ease the import of FM Data into the CMMS.

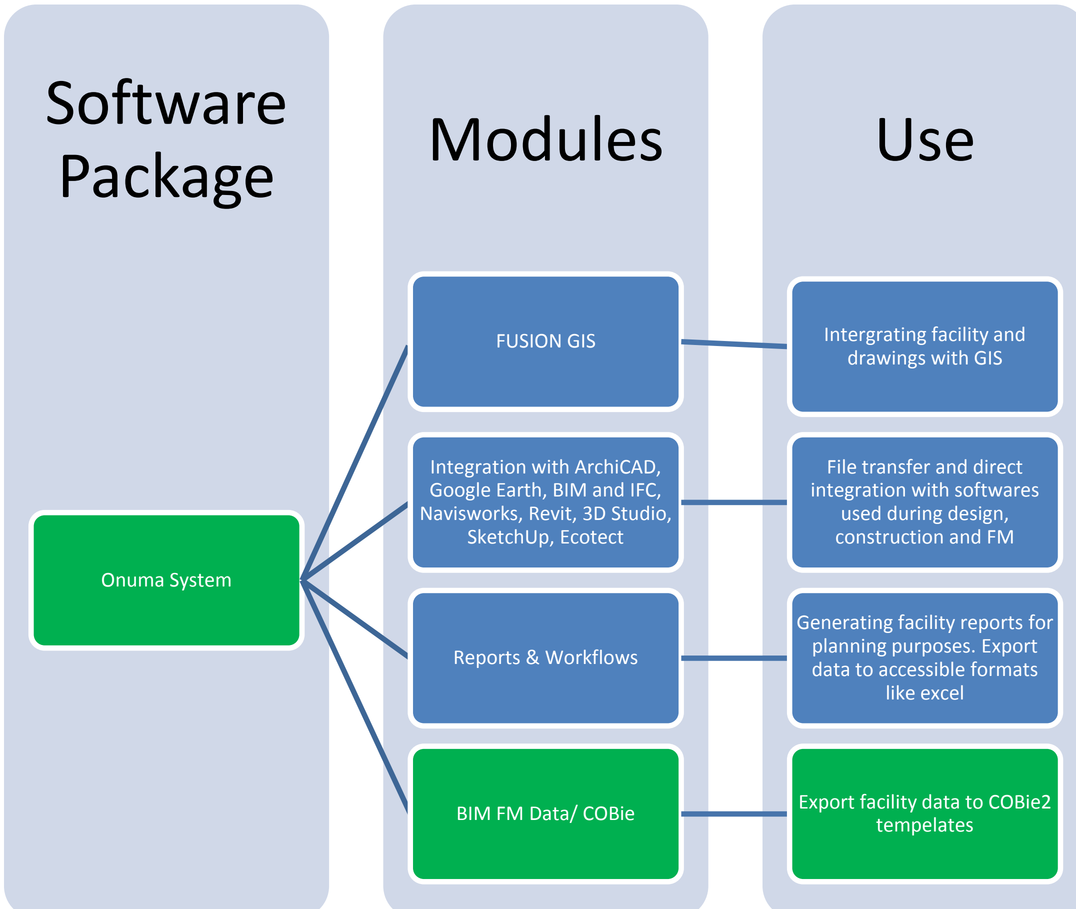


Figure 12 Onuma System.

The intent of these Workbooks is to format data into a COBie2 compliant format. COBie2 is the latest version of the COBie template.

Data for these Workbooks originates from multiple sources:

1. From CAD Models / BIM(s)
2. From other data sources (lists / spreadsheets) of installed equipment
3. From walkthroughs around the facility and collecting data
4. From maintenance personnel working in the facility

5. From equipment catalogs such as RSMeans

The BIM FM Data Templates are organized in the COBie2 and are a direct deliverable to the FM department. The workbooks which constitute COBie2 are as follows: Contact, Facility, Space (includes 'Zones'), Type, Component (including 'Systems'), Attribute, Document, Spare, Resource, Job, Issue. According to the consultant only 6-9% of the COBie data, which predominantly included space allocation information was extracted from the BIM model. The reasons were as follows:

- None of the projects mandated use of BIM technology during design and construction.
- It was not mandatory for the architect/designers to share their BIM's or format them in an IFC format.
- The BIM models which were generated were only for design and construction phases, so they did not have inventory information required for preventive maintenance of equipment.

Onuma System has the functionality to access an Autodesk Revit file directly in its interface and extract inventory and space allocation information stored in it using its 'bimXML' (Buidling Information Modeling Extensible Markup Language) function. This enables a Revit model to be stored in an internet based BIM application, like Onuma. Using this method, space allocation was merged with inventory data collected later and complete COBie file was exported into the CMMS. Appendix D shows the various functionalities of Onuma System.

4.4.2 Ecodomus (Tokmo)

EcoDomus PM ("Project Management"), formerly known as Tokmo, is a software solution dedicated to enabling the usage of Building Information Models (BIM) for new construction, renovation of existing buildings and facility management. It is another software package similar to Onuma System used to formulate COBie 2 data.

EcoDomus was used on the Bryan as another option to Onuma. The interviews did not reveal any specific reason of using two software packages. Moreover, Onuma & EcoDomus are integrated with eachother, which means transfer of data between them is possible so no problems were encountered in using two systems for COBie data formulation. Appendix E shows how EcoDomus integrates BIM, COBie and FM.

4.4.3 Assetworks AiM^{TM}

The Texas A&M Health Science Center's FUSS (Facilities & Construction, Utilities, Safety and Security) use the Assetworks AiM^{TM} Intelligent Workspace Management software package for facility management for all their campuses. AiM^{TM} provides several versions of their software package depending upon business needs, and FUSS opted for their 'Real Estate and Lease Management' version for their campuses. The Bryan as well as the Round Rock campus has some leased spaces to clinics and other healthcare units, which is the reason for opting for this version.

Assetworks offers an added functionality called 'Buidling Information Modeling/COBie Integration', which FUSS used to combine the COBie dataset they obtained from the consultant with AiM^{TM}. The AiM BIM Module allowed FUSS to transfer asset information (COBie2 data) from the Onuma & EcoDomus generated dataset into AiM. AiM was declared fully COBie compliant in 2010 after passing the COBie2 Challenge conducted by the National Institute for Building Sciences (NIBS) and buildingSMART alliance (bSa), which is the reason for FUSS to select this package as their CMSS. This challenge tests both producers and consumers of COBie2 data for their efficiency in integrating COBie formatted data into their system.

4.4.4 TMA Systems

TMA Systems Maintenance Management Software was used by the Facilities Services at the Texas A&M San Antonio Main Building. This software was in use before the COBie dataset formulation process was started, so the facilities services did not have the flexibility to choose their CMMS according to the database requirements. But TMA systems has passed the COBie2 challenge conducted in March 2009 and has the functionality to import a COBie file and populate its dataset, so integration of COBie data should not be a problem of this project. This project is still in its database formulation phase, so it remains to be seen how successful its integration will be with the COBie database.

4.5 Effect on Work Order Response Time

The consultant in collaboration with the FUSS of the Texas A&M Health Science Center conducted a short case study about projected savings in time of handling work orders with the use of a COBie dataset with information extracted from BIM's and other sources of information from the construction phase. It involved the following steps:

- Hold discussions and interviews with the FUSS staff and formulate a typical work order (WO) process in the form of a flowchart including related activities according to their experience.
- Send these flowcharts to facility managers working on different campuses in the Texas A&M Health Science Center and record their responses regarding savings in time in the work order process due to the use of COBie and BIM.

Respondents were also asked to mark the activities in the WO process which they think might be affected due to the use of COBie and BIM. Figure 13 shows the work order process without the use of COBie formulated from the discussions with the FUSS. It lists the activities in a typical WO process in a facility where a COBie dataset is not yet implemented into the CMMS.

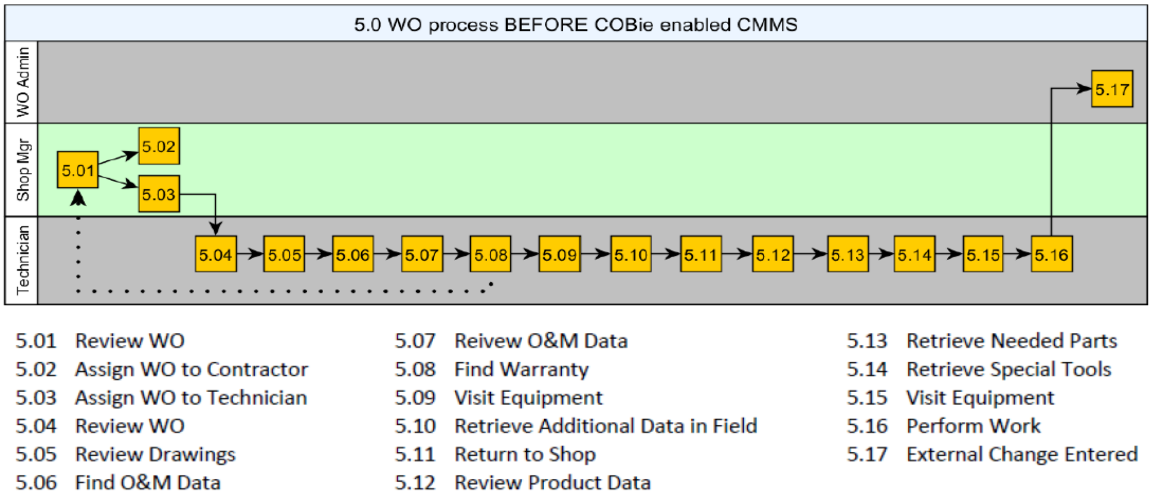


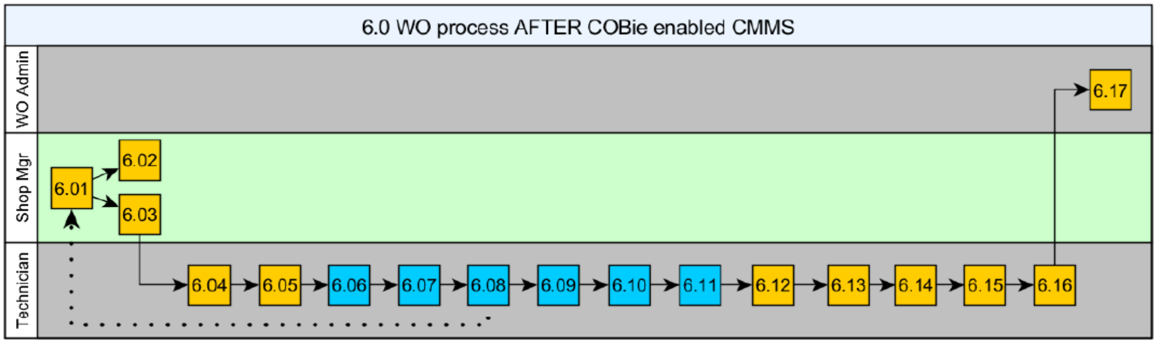
Fig 13 WO process before COBie enabled CMMS.

Table 2 lists the responses from facility managers of the Dallas, Bryan and McAllen campuses of the Health Science Center regarding predicted time for each activity in a WO process without the use of COBie.

Table 2 WO process before COBie enabled CMMS.

WO process BEFORE COBie enabled CMMS				Dallas	Bryan	McAllen	
Activity ID	Activity	Predecessor	Responsibiltiy	Estimated Time (min)	Estimated Time (min)	Estimated Time (min)	Average Time
5.01	Review WO	Start, 5.08	Shop Manager	5	5	5	5
5.02	Assign WO contractor	5.01	Shop Manager	15	12.5	16	14.5
5.03	Assign WO to technician	5.01	Shop Manager	5	5	2	4
5.04	Review WO	5.03	Technician	5	5	2	4
5.05	Review drawings	5.04	Technician	2	11	10	7.7
5.06	Find O & M	5.05	Technician	1	3	2	2.0
5.07	Review O & M	5.06	Technician	1	5	2	2.7
5.08	Find Warranty	5.07	Technician	3	2	2	2.3
5.09	Visit equipment	5.06	Technician	1	1.25	0.75	1
5.10	Retrieve product data from equipment	5.09	Technician	0.75	1.25	1	1.0
5.11	Return to shop	5.10	Technician	0.75	1.25	1	1.0
5.12	Review product data	5.08, 5.11	Technician	10	12	13	11.7
5.13	Retrieve needed parts	5.12	Technician	5	10	15	10
5.14	Retrieve special tools	5.13	Technician	3	3	2	2.7
5.15	Visit equipment	5.14	Technician	10	20	5	11.7
5.16	Perform work	5.15	Technician	45	30	60	45
5.17	External change entered	5.16	WO Admin	3	2	7.5	4.2
	Total			115.5	129.25	146.25	130.3

Thus according to the table above, the average time required to close-out any type of work order, in the opinion of the respondents is 130.3 minutes. Now in comparison to this, the respondents were asked to predict which of the activities in a typical WO process will be affected by the use of COBie and predicted time savings in those activities. Figure 14 and Table 3 show the results obtained. In figure 14 the activities colored blue are the ones which will be affected due to the use of a COBie dataset according to the respondents. These are as follows: Find O&M data, Review O&M data, Find warranty, Visit equipment, Retrieve additional data in field and Return to shop.



6.01 Review WO
6.02 Assign WO to Contractor
6.03 Assign WO to Technician
6.04 Review WO
6.05 Review Drawings
6.06 Find O&M Data
6.07 Reivew O&M Data
6.08 Find Warranty
6.09 Visit Equipment
6.10 Retrieve Additional Data in Field
6.11 Return to Shop
6.12 Review Product Data
6.13 Retrieve Needed Parts
6.14 Retrieve Special Tools
6.15 Visit Equipment
6.16 Perform Work
6.17 External Change Entered

Fig 14 WO process after COBie enabled CMMS.

Table 3 shows the predicted savings in time for a WO.

Table 3 WO process after COBie enabled CMMS.

WO process AFTER COBie enabled CMMS				Dallas	Bryan	McAllen	
Activity ID	Activity	Predecessor	Responsibiltiy	Estimated Time (min)	Estimated Time (min)	Estimated Time (min)	Average Time
6.01	Review WO	Start	Shop Manager	5	5	5	5
6.02	Assign WO contractor	6.01	Shop Manager	15	12.5	10	12.5
6.03	Assign WO to technician	6.01	Shop Manager	5	5	2	4
6.04	Review WO	6.03	Technician	5	5	2	4
6.05	Review drawings	6.04	Technician	1.25	8.5	8.5	6.1
5.06	Find O & M	5.05	Technician	0.26	0.14	0.38	0.3
5.07	Review O & M	5.06	Technician	1	5	2	2.7
5.08	Find Warranty	5.07	Technician	0.25	0.25	0.25	0.3
5.09	Visit equipment	5.06	Technician	0.75	1.25	1	1
5.10	Retrieve product data from equipment	5.09	Technician	0.25	0.75	0.5	0.5
5.11	Return to shop	5.10	Technician	0.75	1.25	1	1.0
6.12	Review product data	6.05	Technician	8.5	7.5	8	8.00
6.13	Retrieve needed parts	6.12	Technician	5	10	15	10
6.14	Retrieve special tools	6.13	Technician	3	3	2	2.7
6.15	Visit equipment	6.10	Technician	10	20	5	11.7
6.16	Perform work	6.15	Technician	45	30	60	45
6.17	External change entered	6.16	External change entered	3	2	7.5	4.2
	Total			109.01	117.14	130.13	118.8

Hence according to the respondents with the use of a COBie enabled CMMS the average time to respond to a WO is 118.8 minutes, which is a reduction of 11.6 minutes/WO or 8.7%.

Though this study is based on the opinion of facility managers at the Dallas, Bryan and McAllen campuses of the Health Science Center, it shows that facility managers have confidence that using the concepts of BIM and COBie will help them reducing WO response times.

5. CONCLUSIONS AND RECOMMENDATIONS

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 construction, but it has many long term advantages throughout the building lifecycle. 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. The following paragraphs outline the major conclusions and recommendations of this study in terms of: Responsibility of database formulation, Characteristics of database (Open standards, Technical knowledge/capabilities, Usability, Database formulation & Technology) and Effect of work order response time. This will be further divided into conclusions and recommendations for each section. Conclusions and recommendations for database formulation and technology are written together because these two aspects are interdependent, so factors affecting technology will affect data formulation and vice versa.

5.1 Responsibility of Database Formulation

Summary of major findings: 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 lifecycle 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 lifecycle – through small projects, operations & maintenance, and major renovations & alterations. The maintenance of this data may create greater efficiencies such as: having accurate as-built information to reduce the cost & time required for renovations, increasing customer satisfaction, and optimizing the operation and maintenance of building systems to reduce energy usage.

Recommendations: Following are recommendations in terms of dividing responsibility among stakeholders of the project to aid database formulation:

- Implement an organization wide framework for contracts which the owner has with the architect, general contractor, subcontractors, fabricators and all 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 lifecycle.

- Ensure that data is created in standard and easily accessible formats like IFC for BIM, pdf for drawings, Microsoft excel for inventory information etc.

5.2 Characteristics of the Database

5.2.1 Open Standards

Summary of major findings: 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.
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 the three projects were successful in the application of the second step, but could not accomplish the first step. 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 15 shows the phases of a project where data formatting and sharing specifications should be followed. Out of the phases mentioned in figure 15, 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 15 Project phases where data formulation should take place.

Recommendations: A solution is to have an organization/campus wide data formulation process which has to be followed by all new construction projects taking place on the campus. This should mandate the following:

1. Use of open standards such as IFC to format BIM models.
2. Mandatory procedures laid out to share installation and commissioning documents in easily accessible interoperable electronic file formats.
3. Communication and Collaboration with the data formulation consultant by all stakeholders of the project, including architect, contractors, subcontractors, fabricators etc. even after the building handover to respond to request for information.
4. Use of COBie importable CMMS.

5.2.2 Technical Knowledge/Capabilities

Summary of major findings: Knowledge of BIM, Open standards of data transfer and CMMS is important for implementing any new concept related to BIM for FM. This was the primary reason for hiring the database formulation consultant by the Facilties and Construction, Utilities, Safety and Security (FUSS) administration of the Texas A&M Health Science Center and the Facilities Services at Texas A&M University, San Antonio. The FUSS and Facilities Services of Texas A&M University, San Antonio, 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 lifecycle, so that the data is usable even after major renovations or changes to the facility.

The Facilities and Construction, Utilities, Safety and Security (FUSS) administration of the Texas A&M 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 the CMMS, and can handle updating the database throughout the building lifecycle. 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.

Recommendations: There are two types of capabilities and knowledge facility personnel should have to efficiently apply BIM and COBie for FM:

- Knowledge of the concepts of BIM and relevant standards and formats, how to formulate and update COBie databases and integrate them with the CMMS.
- Knowledge of inventory information which maintenance personnel require to perform preventive maintenance, emergency work orders, renovations etc. FM departments should not only have personnel with this knowledge but also make them a part of the planning process in database formulation.

5.2.3 Usability

Summary of major findings: The common goal of all the FM departments on the three projects was to formulate a database which would help them 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 facility management 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.

Recommendations: For using BIM and for all of the above mentioned uses, Tier - 1 and Tier - 3 information will also be required instead of just the Tier - 3 information which was gathered (GSA 2011). Following is the Tier - 2 information which was included in the COBie file:

- Equipment information – ID, Make, Model, Serial Number, warranty information, maintenance instructions, etc

Following is the Tier - 1 and Tier - 3 information that should be collected to magnify the usability of the database:

- Tier - 1: Spatial program BIM, Accurate as-built geometry for equipment.
- Tier -3: As-designed BIM with energy analysis predictions.

5.2.4 Database Formulation and Technology

Summary of major findings: Starting the database formulation early during design and construction results in:

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

Though software packages such as Onuma System and EcoDomus were used, their use was limited to a formatting tool for the COBie file and exporting to the CMMS. If complete IFC files of the BIM's are available, Onuma System as well as EcoDomus can be used to store and access them through an internal network or the internet with integration of the CMMS. This won't require installation of any 3D modeling software or high performance workstations and can be accessible within the interface of the CMMS. This magnifies the scope of use of the data to space management, workplace planning, real estate management, equipment mapping etc. instead of just limiting the use to preventive maintenance.

Recommendations: Figure 16 shows the database formulation process which should take place on a project to enable complete utilization of the information contained in a BIM model. All stakeholders of the project like 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 design and construction phase. 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.

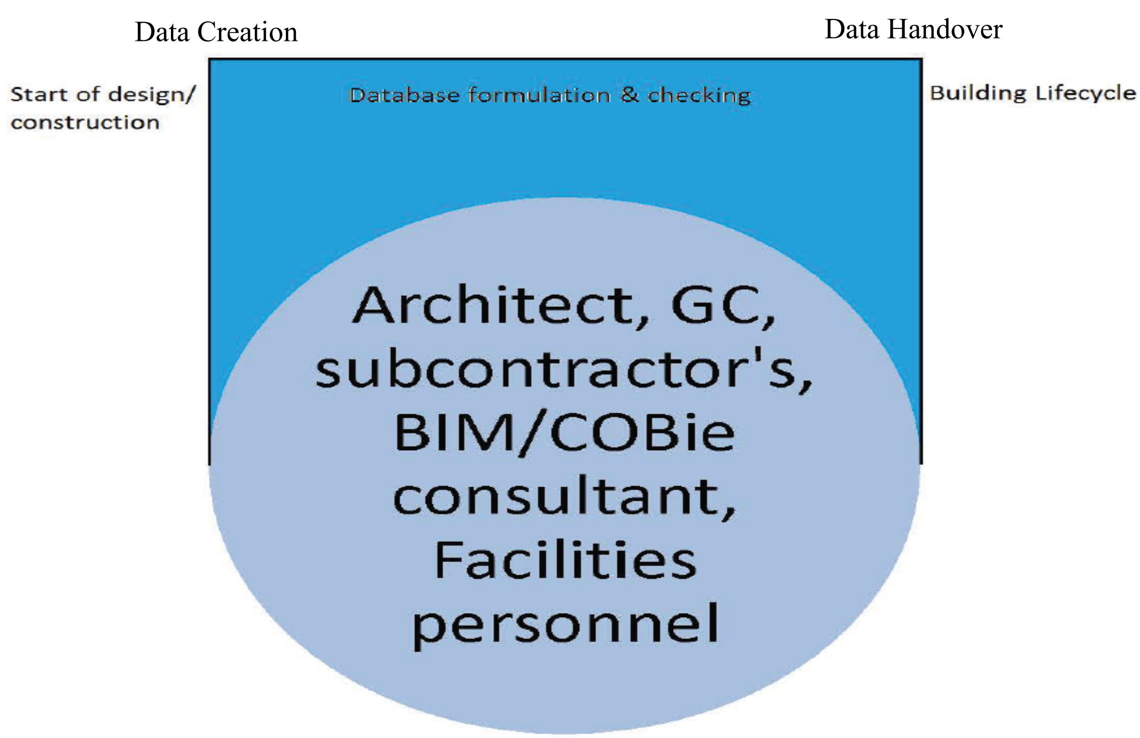


Figure 16 Recommended database formulation process.

Database formulation process and the technology used should incorporate all of the following aspects to enable their maximum use:

- Start early in the project, preferably in the design phase, to gather data to be used during facility management.
- Extract data from different file formats into a COBie file as the data is created using network based softwares like Onuma or EcoDomus. Using these softawares multiple users (architect, general contractor, sub contractor etc.) can make changes to the same database concurrently since the data is "online". This will eliminate any delay in using the data after the building is handed over as the COBie file will be up to date and ready to be integrated into the CMMS as soon as the construction is complete.

With the progress in database formulation technology and by the use of standard and open data formats, there is also a possibility of automating the data collection process. This means that as data is created on the project, it would be stored in an interoperable BIM format, with all relevant equipment information, without the need of a consultant to gather and format the data. The data in the BIM could be directly used by the facility management department. This BIM would be as a single source for data for facility management, and will have modules for FM built into it, without requiring a CMMS or a software tool to extract data from it. It will be a single system used for design, construction & FM and eradicate the problem of interoperability.

5.3 Effect on Work Order Response Time

Summary of major findings: 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, Find warranty, Visit equipment, Retrieve additional data in 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 will be reduced by using a COBie database sourced by data from a BIM and other construction documents. According to these facility managers, the cumulative saving in time responding to a work order will be 11.6 minutes/WO or 8.7%. 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.

Recommendations: Quantifiable data is required to perform research on savings in work order response times. Such research will corroborate 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. This will enable the formation of a database to use for emergency work orders, space management, energy analysis etc. than just preventive maintenance.
- If the data like response times, changes in inventory etc. is stored for this facility through its CMMS. This will enable an adequate amount of quantifiable data available for statistical analysis.

5.4 Significance of Study

This research proves that the use of Building Information Modeling (BIM) for database formulation and Construction Operations Building Information Exchange (COBie) 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 the BIM format if possible, or in agreed interoperable formats through COBie. This will increase the value of the data and also provide savings of time and money in the operations of the building throughout its lifecycle.

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, space management etc.

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APPENDIX A

TEXAS A&M UNIVERSITY
DIVISION OF RESEARCH AND GRADUATE STUDIES - OFFICE OF RESEARCH COMPLIANCE

1186 TAMU, General Services Complex
College Station, TX 77843-1186
750 Agronomy Road, #3500

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Human Subjects Protection Program

Institutional Review Board

APPROVAL DATE: 15-Jul-2011

MEMORANDUM

TO: JAWADEKAR, SALIL
77843-3578

FROM: Office of Research Compliance
Institutional Review Board

SUBJECT: Initial Review

Protocol Number:	2011-0314
Title:	Building Information Modeling (BIM) for Facility Management
Review Category:	Expedited
Approval Period:	15-Jul-2011 **To** 14-Jul-2012

Approval determination was based on the following Code of Federal Regulations:

45 CFR 46.110(b)(1) - Some or all of the research appearing on the list and found by the reviewer(s) to involve no more than minimal risk.

Criteria for Approval has been met (45 CFR 46.111) - The criteria for approval listed in 45 CFR 46.111 have been met (or if previously met, have not changed).

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(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation or quality assurance methodologies.

(Note: Some research in this category may be exempt from the HHS regulations for the protection of human subjects. 45 CFR 46.101(b)(2) and (b) (3). This listing refers only to research that is not exempt.)

Provisions:

Comments:

This research project has been approved for one (1) year. As principal investigator, you assume the following responsibilities

1. **Continuing Review:** The protocol must be renewed each year in order to continue with the research project. A Continuing Review along with required documents must be submitted 30 days before the end of the approval period. Failure to do so may result in processing delays and/or non-renewal.
2. **Completion Report:** Upon completion of the research project (including data analysis and final written papers), a Completion Report must be submitted to the IRB Office.
3. **Adverse Events:** Adverse events must be reported to the IRB Office immediately.
4. **Amendments:** Changes to the protocol must be requested by submitting an Amendment to the IRB Office for review. The Amendment must be approved by the IRB before being implemented.
5. **Informed Consent:** Information must be presented to enable persons to voluntarily decide whether or not to participate in the research project.

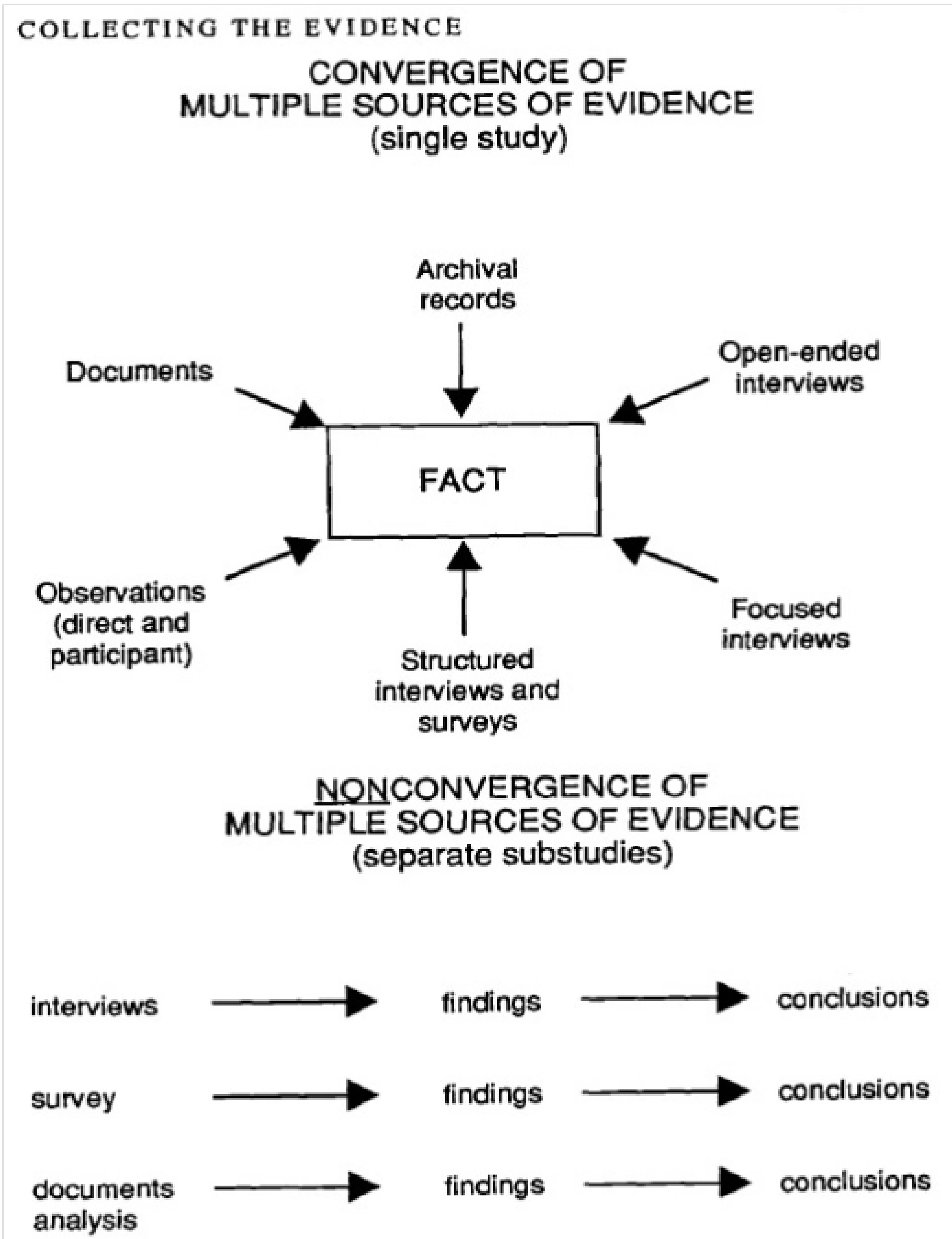
This electronic document provides notification of the review results by the Institutional Review Board.

APPENDIX B

Typical Case Study Questions

1. Who were the parties involved at each stage of the project or initiative? How did FM requirements influence the development of the BIM models? What role did the owner play in setting the FM requirements and the role of FM staff?
2. In the case of new construction or remodeling, what were the design innovations (if any)? Were there energy, sustainability or environmental aspects that required special study and thus required significant application of analysis or simulation tools? Describe how the design interacted with these tools. How were these issues reflected in (or driven by) FM requirements?
3. How was collaboration realized, with focus on the coordination between FM and the design and construction team; what software was used to facilitate collaboration?
4. Did any of the participating firms apply metrics regarding time, errors, design changes, cost to the project to calibrate how well they did? Were there any significant time or cost savings or overruns as a result of using BIM for FM? If so, can this information be made available?
5. What were the major lessons learned from this project?
6. What would they (facility manager, owner, project participants) do differently next time?

APPENDIX C



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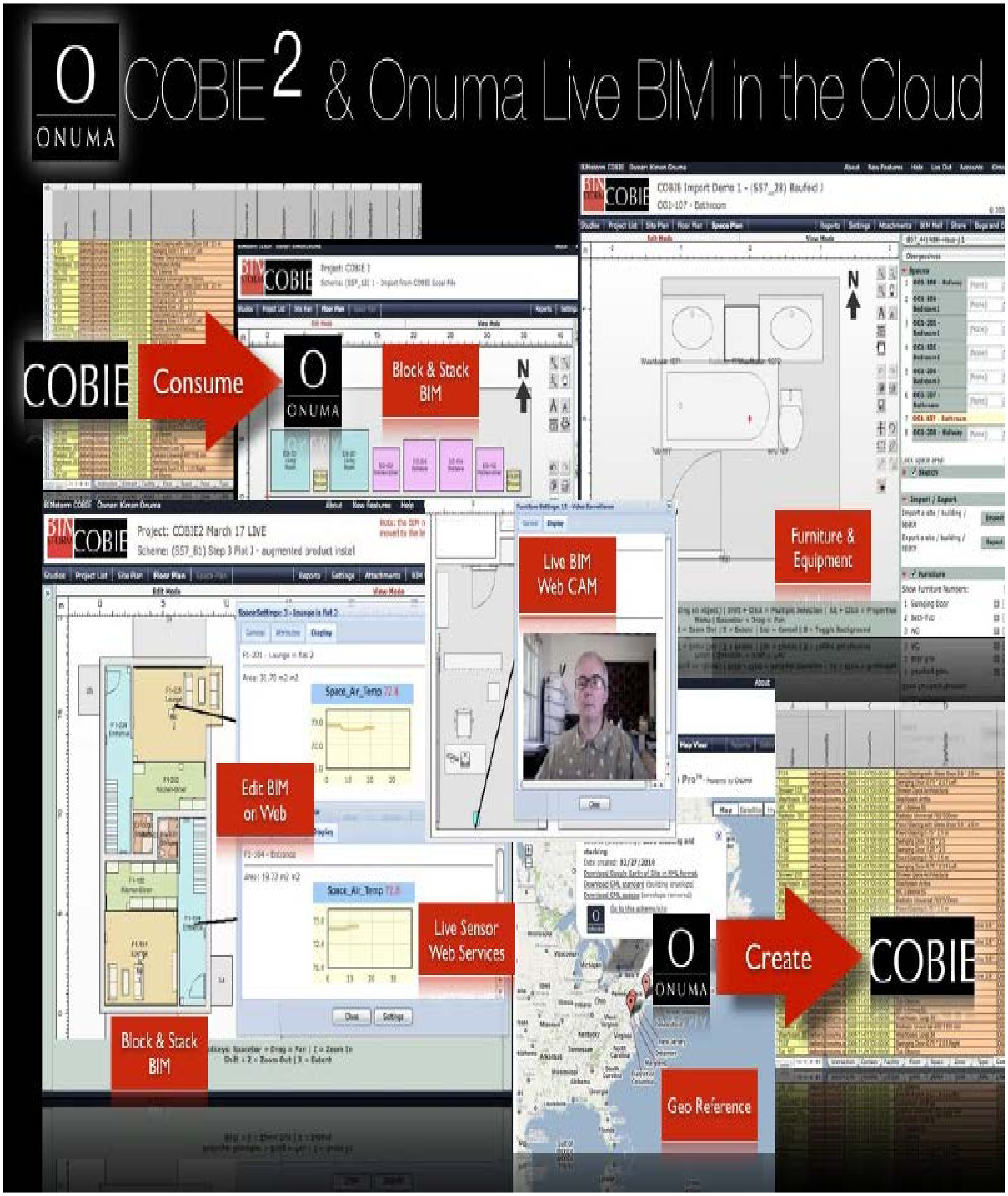
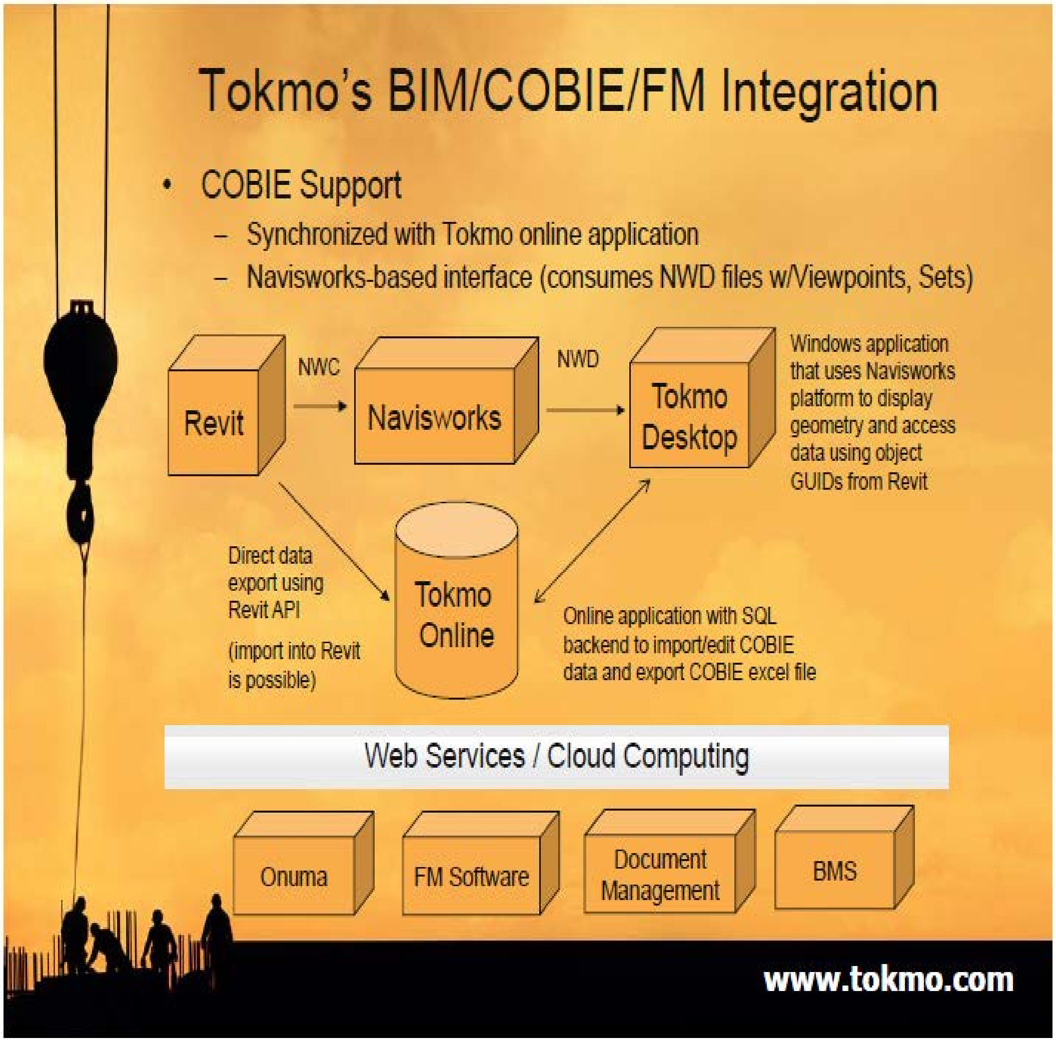
APPENDIX D


COBIE2 & Onuma Live BIM in the Cloud
ONUMA
COBIE
Consume
Block & Stack BIM
Furniture & Equipment
Live BIM Web CAM
Edit BIM on Web
Live Sensor Web Services
Block & Stack BIM
Create
Geo Reference

APPENDIX E


Tokmo's BIM/COBIE/FM Integration
• COBIE Support
– Synchronized with Tokmo online application
– Navisworks-based interface (consumes NWD files w/Viewpoints, Sets)
Revit
NWC
Navisworks
NWD
Tokmo Desktop
Windows application that uses Navisworks platform to display geometry and access data using object GUIDs from Revit
Direct data export using Revit API
(import into Revit is possible)
Tokmo Online
Online application with SQL backend to import/edit COBIE data and export COBIE excel file
Web Services / Cloud Computing
Onuma
FM Software
Document Management
BMS
www.tokmo.com

VITA

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Education:	B.E Civil Engineering, Sardar Patel College of Engineering, University of Mumbai, 2009 M.S. Construction Management, Texas A&M University, 2012