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PERCEIVED VALUE OF BUILDING INFORMATION MODELING IN FACILITIES OPERATIONS AND MAINTENANCE

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BY

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B.S. - CIVIL ENGINEERING
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THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of

Master of Sciences
Civil Engineering

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November 2010

DEDICATION

Quiero dedicar este trabajo a mi familia Wanda, Pablo y Luisa. Su constante apoyo ha hecho que tenga la motivacion para completar este trabajo. No existen las palabras suficientes para expresar cuanto los aprecio y lo mucho significan en mi vida.

Dios siempre nos mantenga juntos,

Los quiero mucho

Francisco

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Conventional practices and inefficiencies in accessing relevant operation and maintenance (O&M) information are major issues to maintain facilities for their intended purpose. The need to have access to accurate information efficiently is critical to operate and maintain a facility. Building Information Models are databases able 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. The purpose of this research is to determine the perceived value by owners of using BIM for facilities O&M. This research surveyed 125 facilities operations personnel to determine their perception on future use, time savings and benefits of using BIM for facilities O&M.

The research reviewed related literature that included books, peer reviewed journal articles, case studies, web-seminars and manuals. The interviews were conducted with five experts in operating and maintaining facilities. Based on this information, an online survey was developed and distributed to facilities operations personnel. The survey included a video that demonstrated the future use of BIM for facilities O&M.

This research indicated that more than two thirds of the respondents would use BIM frequently to access O&M information, the work order process work flow can be reduced by twenty five percent and the response time to unscheduled work orders can be reduced by using BIM. Most respondents perceived improved accessibility to O&M information is the best benefit of using BIM for O&M.

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LIST OF ACRONYMS & KEY TERMS

2D, 3D, 4D, 5D	Two, three, four, five dimensions
ADA	American with Disabilities Act
AEC/FM	Architecture, Engineering, Construction and Facilities Management
BIM	Building Information Modeling
CAD	Computer Aided Design
CMMS	Computerized Maintenance Management System
CRC	Cooperative Research Center
EPA	Environmental Protection Agency
FIATECH	Fully Integrated and Automated Technology
FEMP	Federal Energy Management Program
FM	Facility Management
IPD	Integrated Project Delivery
NBIMS	National Building Information Modeling Standards
NIST	National Institute of Standards and Technology
NIBS	National Institute of Building Sciences
NRC	National Research Council
O&M	Operations and Maintenance
OSHA	Operational Safety and Health Administration
PM	Preventive Maintenance
PPD	Physical Plant Department
RFI	Request for Information
SPSS	Statistical Package for Social Sciences
UNM	University of New Mexico
WO	Work Order

CHAPTER 1 INTRODUCTION

1.1 Overview

Conventional practices and inefficiencies in accessing relevant operation and maintenance (O&M) information are major issues to maintain facilities for their intended purpose. In addition, today's buildings are increasingly becoming more complex. Managing constructed facilities requires a wide range of activities and information. Thus, the need to have access to information efficiently is vital to operate and maintain a facility. Unlike the design and construction phase, the information needed for O&M extends through the lifecycle of the facility. Furthermore, the cost of operating and maintaining a facility represents approximately 85% of the total cost of ownership (P.Teicholz, 2001).

Providing O&M information in an electronic format can improve efficiencies; however, problems often arise due to a lack of interoperability of systems. The National Institute of Standards and Technology (NIST) estimated a $15.8 billion additional cost of interoperability in capital facilities (Gallagher, O'Connor, Dettbarn, & Gilday, 2004). Of the estimated $15.8 billion, owners and operators incurred approximately $10.6 billion or 67% of the total cost of interoperability. The efficiency loss was attributed to time spent on information verification and validation, costly information delay to employees waiting for the necessary information to resolve a maintenance issue, inefficient business process management and the use of redundant information technology systems (Gallagher et al., 2004).

FIATECH (Fully Integrated and Automated Technology) has studied some of the major issues of system information interoperability in the building industry. The accessibility, availability and reliability of accurate information through the lifecycle of a construction project constitute some of the major problems. A methodology to manage the lifecycle information of a construction project does not exist. In addition, there is a lack of understanding of the issues in a facility lifecycle. Consequently, operation, maintenance, environmental impact and commissioning issues are not given the necessary consideration and importance. Finally, lack of knowledge and limitations of current tools prevent the assessment of uncertainties, risks and possible failures (Shen et al., 2010).

Many authors attribute that lack of information interoperability is due to the slow application of technological innovations (Eastman, P. Teicholz, Sacks, & Liston, 2008). It is widely known that information technologies have changed the way manufacturing and service providers perform their work nowadays. The automobile, aircraft and computer industries have taken the lead in successfully applying technological information systems through their lifecycle processes (Gallagher et al., 2004). The architecture, engineering, construction and facility management (AEC/FM) industry has advanced slowly compared to these industries in their technological innovations. However as a project-based industry, the AEC/FM industry follows the same trend as other project-based industries (Taylor & Levitt, 2004)

In addition, the fragmented nature of the AEC/FM industry has prevented the integration of all required information through the building lifecycle. This fragmentation increases time and effort to respond rapidly and efficiently to project challenges. The

AEC industry has taken different approaches to overcome this fragmentation. Integrated Project Delivery (IPD) is a recent project delivery system that promotes key participants to contribute their experience, knowledge and proactive involvement in the early phases of a project. IPD has allowed project participants to work and communicate in a collaborative environment, but also, it has facilitated integration and exchange of information with the information technologies used in the building industry. However, there have not been enough efforts to efficiently transfer this information to the facilities O&M.

Building Information Modeling (BIM) is considered one of the most promising technological developments in the AEC/FM industry (Eastman et al., 2008). BIM represents a business process that essentially changes the traditional way that the owner, designers and contractors, fabricators and operators interact. The early participation of these key team members before the design phase begins is critical to address and identify challenges before construction begins. BIM provides an improved capability to control scope, functionality and cost, while reducing the cost of design changes and coordination. BIM is defined as “a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its lifecycle from inception onward” (www.buildingsmartalliance.org). A model comprises information properties such as function, shape, material and processes to support the building lifecycle, and can be interpreted by computer applications (Isikdag & Underwood, 2009). Additionally, it collects information during design and construction that can be used throughout the lifecycle of a building.

The implementation of BIM has proven to be successful in the design and construction phase. The main advantage of building information modeling from other design technologies is “the structured information that is organized, defined and exchangeable” (Smith & Tardif, 2009).

The greater benefits in design and construction are in reduced change orders, reduced request of information (RFI’s), improved productivity, reduced conflicts/changes during construction and use of clash detection to avoid rework (Young, S. A. Jones, Berstain, & Gadgel, 2009). McGraw Hill reported that almost 50% of the industry is now using BIM in their companies. Conversely, the main reason that AEC companies are not using BIM yet is because owners do not demand it (Young et al., 2009). In the last years, most owners have learned what BIM can do for design and construction; projects are delivered faster, at a lower cost and with better quality. But downstream many do not know how it can better enable them to perform their day-to-day duties in the O&M of their facilities. There is a lack of understanding how these benefits can be transferred to the O&M phase.

In addition, the lack of documented measures on the value of BIM for facilities management has slowed owners' adoption of BIM despite their great interest in using BIM data to support the O&M phase (Jordani, 2010). Based on my research, the use of BIM for O&M has not been widely implemented; the concept is viewed as vision more than a reality, but is expected to change in the near future. As a result, measures on proven benefits of BIM for O&M cannot be determined based on my research. But the concept of BIM as a “database that stores, links, extracts and exchanges information”, presents great opportunities for O&M (Foster, 2010).

While BIM presents great opportunities to establish a new approach to manage O&M data efficiently during the lifecycle of a building, there is a need for additional information from owners to help support its adoption. The results of this research would provide valuable metrics, increase owners' awareness, document potential barriers and promote creative solutions to use BIM data to manage O&M procedures during a building's lifecycle.

1.2 Research Objective

The objective of this research is to collect information from facilities operations personnel to aid in the future use of BIM for O&M. The questions the research aims to answer are the following:

- How often would facilities operations personnel use BIM to access O&M information?
- What percentage of time could facilities operations personnel save in the work order process by using BIM?
- What effect would BIM have in the response time to unscheduled work orders?
- What are the potential benefits of using BIM for O&M?

Secondly, this research expects to obtain information about the following topics:

- Explore current O&M practices
- Rating of current accessibility to O&M information and accuracy of as-built drawings
- Assess the facilities operations personnel familiarity with BIM.

The intent is to determine the perceived value and future benefits of using BIM as a way to visualize and access valuable O&M information in order to encourage owner’s implementation of BIM.

1.3 Methodology Overview

The assessment of the perceived value of BIM for O&M utilized qualitative and quantitative data. The data were collected through literature review, interviews and online survey of people working in facilities O&M. The extensive review of the related literature included books, peer reviewed journal articles, case studies, web-seminars and manuals. The background interviews were conducted on people with expertise in operating and maintaining facilities. In addition, informative presentations were given to O&M groups about the use of BIM for facility management and follow up discussions were had.

The online survey was developed with the information obtained from the literature review and the background interviews. The online survey consists of an initial set of questions on facility characteristics, current O&M activities and building information modeling. Follow-up sets of questions were answered after watching a short "View of the Future for FM" video (Foster, 2010). The video uses an example work order for a suspected leaky pump in a mechanical room; it demonstrates how BIM could be used for FM in the future.

Experts validated the survey as the data collection instrument using face and content validity and the use of test-retest for reliability. After the survey was tested it was distributed through professional organization, websites, web seminars, blogs and forums across the United States.

Pearson Chi-Square tests were performed to analyze the data in order to establish relationships and descriptive statistics including calculations of the median, mean and standard deviation.

CHAPTER 2 BACKGROUND INFORMATION

2.1 Overview

The concept of using building information modeling for facilities management is relatively recent. Consequently, the number of articles and case studies related to the purpose of this study are limited. Nevertheless, the future opportunities of using BIM for FM are infinite. It is expected that future research will emphasize the use of BIM for FM. This chapter will provide background information, literature review and case studies on the following topics:

- Building Information Modeling
- Facilities Operations & Maintenance
- Interoperability

2.2 Building Information Modeling

2.2.1 Definition

The term BIM first came to popular use in 2002, when it was defined "as a common name for a digital representation of the building process to facilitate exchange and interoperability of information in a digital format" (Eastman et al., 2008). However, the concept of what today is known as BIM dates back from the late nineteen seventies. In 1975, some of the first concepts were introduced as (Eastman et al., 2008):

[designing by] "…interactively defining elements…deriv[ing] sections, plans, isometric or perspectives from the same description of elements…Any change of arrangement would have to be made only once for all future drawings to be updated. All drawings derived from the same arrangement of elements would automatically be consistent…any type of quantitative analysis could be coupled directly to the description…cost estimating or material quantities could be easily generated…providing a single integrated database for visual and quantitative analyses…automated building code checking in city hall or the architect's office. Contractors of large projects may find this representation advantageous for scheduling and material ordering."

During the eighties and nineties Eastman redefined this approach to "Building Product Models" (Eastman et al., 2008). A product model is defined as a "digital model of a product comprising all relevant information of a product…", almost the same concept of what a building information model represents today. According to (van Nederveen, Behesti, & Gielingh, 2009), some of the concepts of BIM have derived from product modeling, technology that has been applied early in other industry sectors such as mechanical engineering, aerospace, automotive and shipbuilding.

The National Institute of Building Sciences (NIBS) Committee recently published the first version of National Building Information Standards (NBIMS V1-P1). In this document the NBIMS Initiative categorizes the BIM scope in three ways, "as product, as an IT enabled, open standards based deliverable, a collaborative process, and a facility lifecycle management requirement"(NBIMS, 2008). For the purpose of this research a BIM is defined as a "digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward" (NBIMS, 2008).

2.2.2 BIM Concepts and Benefits

As discussed above, the concept of BIM was developed in the late nineteen seventies. The concept is based on object-based parametric modeling. Within this concept objects are represented by parameters that determine geometric and non-geometric characteristics. These parameters allow objects to update automatically when the user makes a change to the object (Eastman et al., 2008). Mendez (2006) made an analogy of the parametric concept with Microsoft Excel, "where a change in one cell can automatically be reflected in the entire series of cells (or worksheets) without obligating the user to manually change all related cells to show the new modification in the Excel file".

In the architecture practice, the use of parametric modeling has facilitated designers/drafters to make updates to their designs. For instance, when a change is made in a section of a drawing all the changes are reflected throughout the rest of the project in all views. In addition to the 3D representations of building components, BIM also contains information that is captured and transferred throughout the project lifecycle (Krygiel & Nies, 2008). The additional information can be assigned to the geometric representations. For instance, a building component such as a door can contain information about material, finishes and manufacturer information. Additional information such as area, length and size can be linked and extracted from the element.

In addition, BIM software providers have developed object libraries that contain pre-defined sets of building components such as walls, doors, floors, foundations, etc. These objects can be easily modified according to the users' preferences. Users can also create their own parametric-based objects for their own purposes and use it for quality control and best practices. A basic concept of BIM is collaboration by project participants at different stages of the life cycle of a facility to “insert, extract, update or modify information in the BIM process” to support and reflect the roles of that project participant (NBIMS, 2008). The BIM is a shared digital representation based on open standards for interoperability (NBIMS, 2008).

The use of 3D parametric object modeling had a significant impact on productivity in detailing and on improving the coordination of the design process. Mokbel (2003) discovered that one third of the scope changes on a specific project were primarily due to poor coordination. This study revealed the significance of inconsistent design documentation with respect to changes in the project and how this could be significantly reduced by the use of a 3D parametric object modeling.

The major difference with 2D design software such as AutoCAD is that drawings are based on geometric models such as lines, arcs, circles, etc. These objects are not automatically updated, thus making changes in a geometric model is time consuming and vulnerable to errors. Traditionally, the building industry uses 2D drawings and computer aided design (CAD) files to coordinate and transfer information between project participants as seen in Figure 1. However, the nature of 2D creates situations in which complex details are not satisfactorily represented. The current use of 2D drawings is prone to uncertainty because information can be easily misinterpreted. This information has the risk to be inconsistent, especially when information is exchanged between different project participants (van Nederveen et al., 2009). Tse (2005) determined that the increase of design consistency was one of the most important reasons why architects used BIM. Furthermore, 2D drawings are not able to provide all the information required to be used in the lifecycle of a building. Smith & Tardif (2009) pointed out that architects and engineers could improve design team communication and collaboration by replacing 2D paper-based representations with 3D geometric representations with BIM. Figure 2 illustrates the use of 3D BIM to resolve physical interferences.

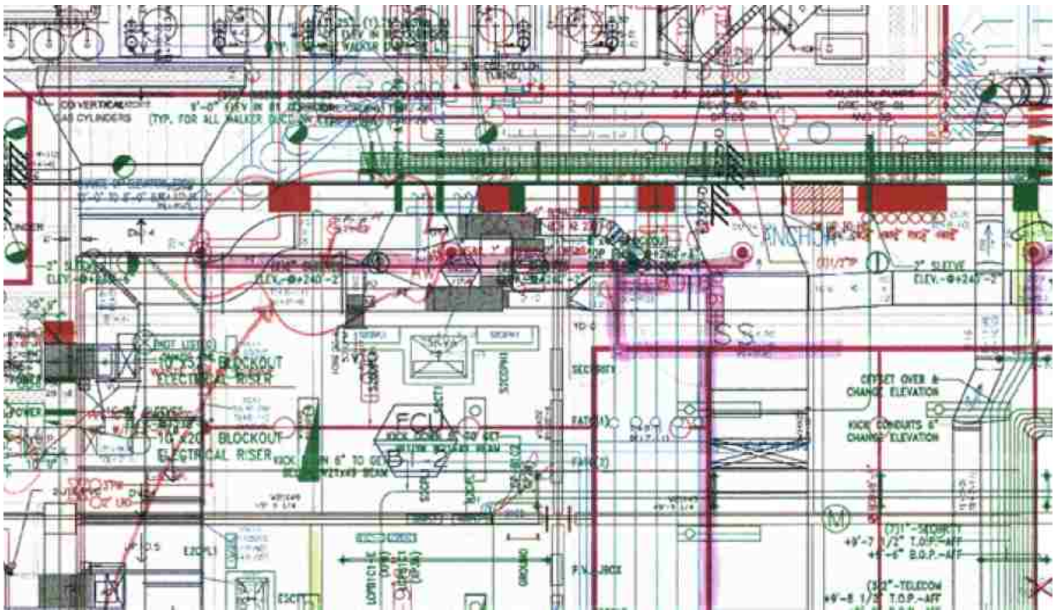

Figure 1: Identifying and resolving physical interferences using 2D drawings - Courtesy of Jim Bedrick Webcor Builders

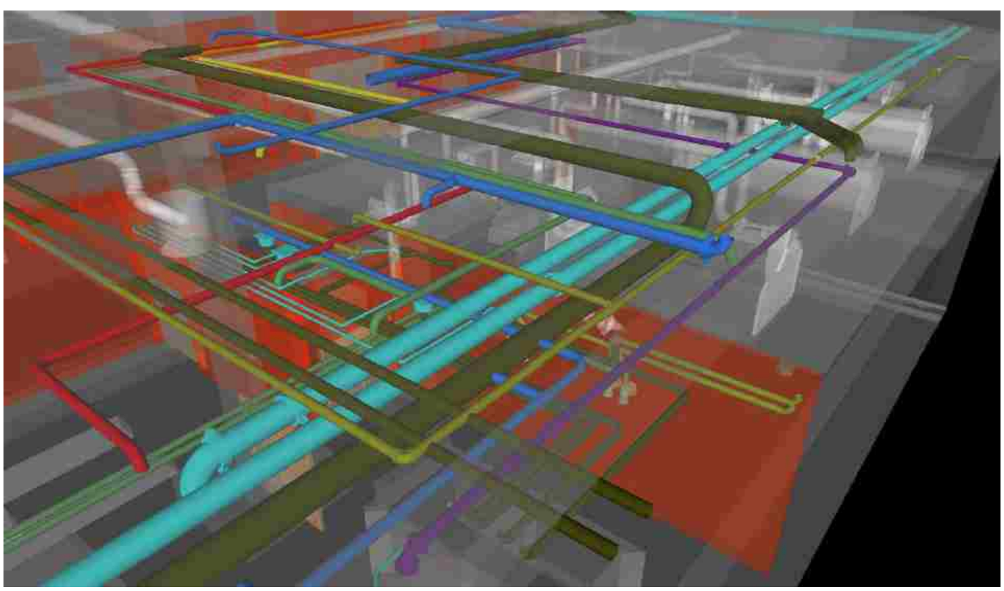

Figure 2: Resolving physical interferences using 3D BIM - Courtesy of Jim Bedrick Webcor Builders

In the last five years BIM has evolved rapidly, becoming one of the most important topics in the AEC/FM industry. During these years, many researchers, software providers, design and construction firms have been investing in the development and use of this technology. The main advantage of BIM that differentiates it from other design technologies is "the structured information that is organized, defined and exchangeable" (Smith & Tardif, 2009). BIM benefits are rooted in providing more complete and accurate information earlier in the delivery process, in order to reduce the costs of changes. Figure 3 shows this idea. Line 1 on the graph represents the inverse relationship between time and the ability to make changes. The ability to make changes is higher the early phases of a project and reduces as the project moves forward. Line 2 shows how the cost increases as the project moves forward.

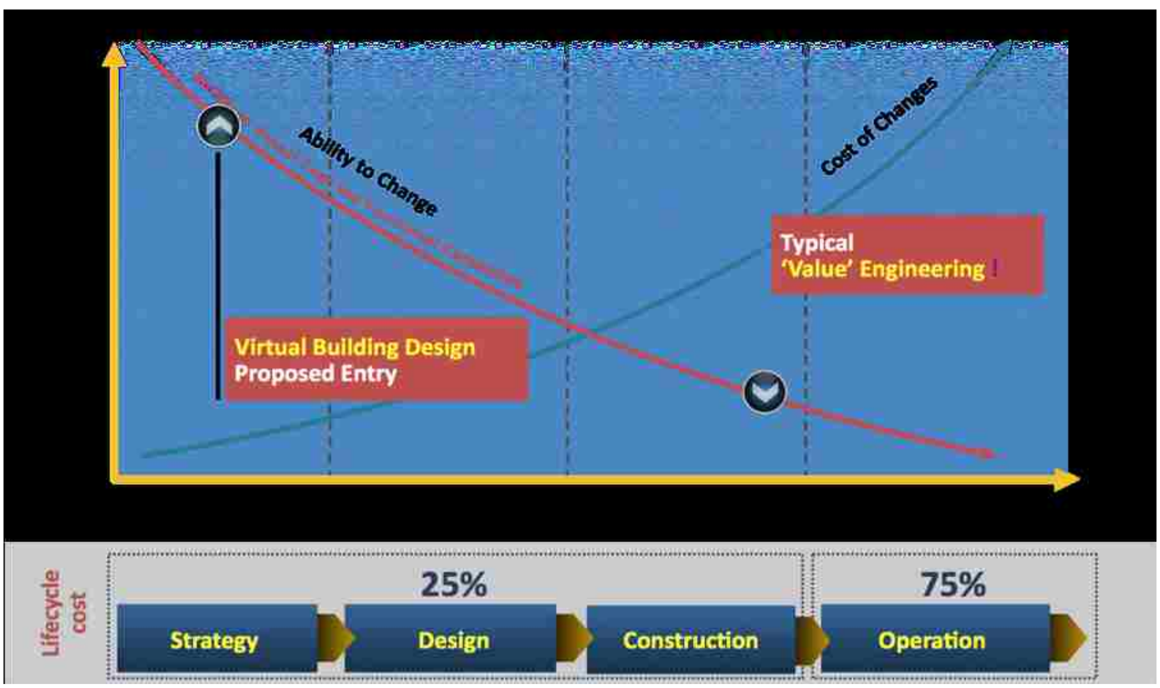

Figure 3: Ability to Make Changes and Cost of Changes – Courtesy of Deke Smith

The principle of BIM is gather necessary information from all project participants to make changes in the early phases of a project in order to reduce costs.

BIM can be used for: design visualization, design assistance and constructability review, site planning and site utilization, 4D scheduling and sequencing, 5D cost estimating, integration of subcontractor and supplier models, systems coordination, layout and fieldwork, prefabrication, operations and maintenance (Campbell, 2007).

In 2009, McGraw Hill's SmartMarket Report published the "The Business Value of BIM: Getting Building Information Modeling to the Bottom Line", the report presented the current practice of BIM in the building industry. According to the report, almost half of the building industry is using BIM, 67% see a positive return on investment in implementing BIM and nine out of ten users believe that it BIM has the capability to bring more benefits in the future.

Many users report that BIM has brought a competitive advantage by marketing new business to clients, 50% stated that it has helped them offer new services and 70% believe that it has helped them to maintain a long-term relationship with their clients. Seventy percent of contractors and owners see a positive return of investment in using BIM compared to architects (58%) and engineers (46%).

The top rated BIM benefits that improve the return of investment are: 1) Better multiparty communication and understanding from 3D visualization, 2) Improved project process outcomes, such as fewer RFIs and field coordination problems 3) Improved productivity of personnel and 4) Increased prefabrication. BIM provides numerous benefits but by consensus these are the top rated: 1) Reduced conflicts during construction (Figure 4), 2) Improved collective understanding of design intent, 3)

Improved overall project quality, 4) Reduced changes during construction and 5) Reduced number of RFI's (Young et al., 2009).

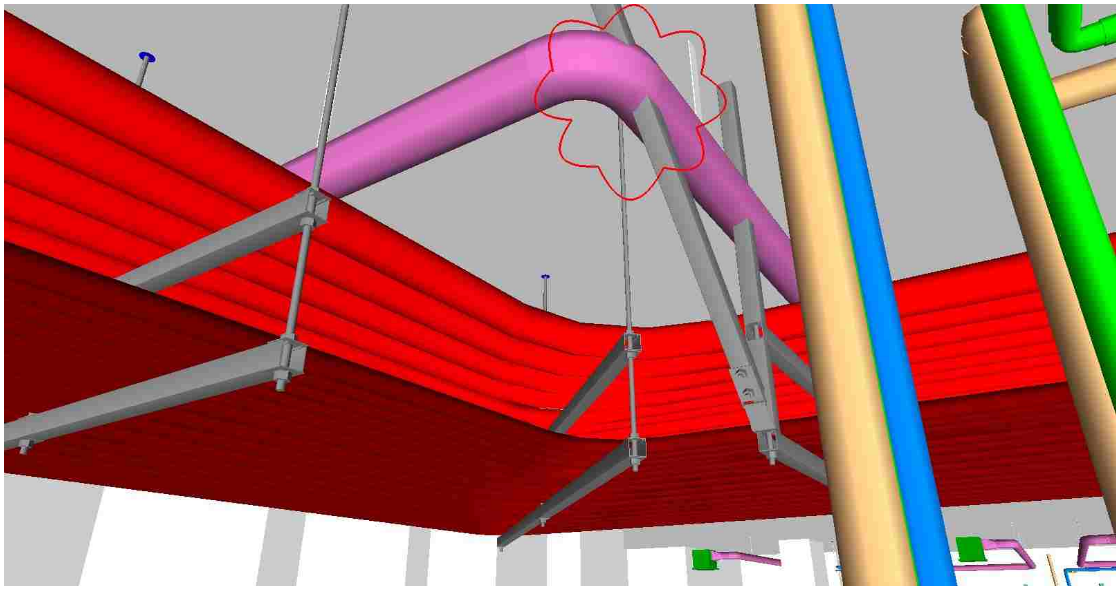

Figure 4: Clash detection is one of the top benefits to reduce conflicts in construction – Courtesy Birgitta Foster

2.2.3 Building Information Modeling for Facility Management

Based on the positive impact of BIM in design and construction, owners and facility managers are searching for ways to extend the benefits downstream to improve the management and O&M phases of a facility's lifecycle. The lifecycle aspect of BIM is what differentiates it from preceding digital technologies. The amount of structured building information captured during design and construction can provide an opportunity of using that information for maintaining and operating throughout the facility lifecycle (Smith & Tardif, 2009). According to (A. Lee, Wu, Aouad, Cooper, & Tah, 2006) the use of traditional fragmented processes that use manual and 2D documents present major challenges to maintain facilities accordingly to their intended goal. Figure 5 and Figure 6 illustrate traditional uses of O&M information.

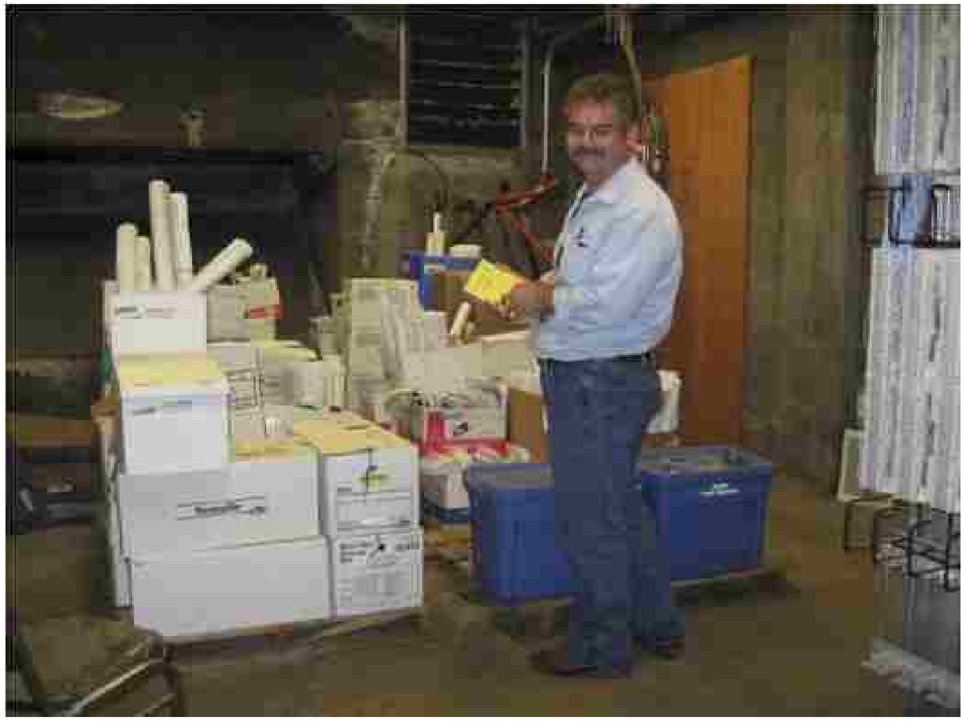

Figure 5: Traditional use of O&M information and as-built drawings – Courtesy of Dr. Bill East, USACE ERDC Champlain, Il.

Facility managers are handed over a series of project documents that has been transferred from one phase to another. This conventional approach to manage and exchange information between phases causes major issues in which information is inconsistent and lost in the process (Olatunji & Sher, 2009). The objective of BIM is to have complete information about a product in this case a building component in which the information is “formal, consistent, non-ambiguous and non-redundant” (van Nederveen et al., 2009).

Figure 6: Current access to O&M manuals at UNM

Becerik-Gerber & Kensek (2010) identified the potential areas of research and future trends in BIM in the AEC industry. BIM for FM was one of the topics of least interest by AEC practitioners and students, mainly because owners did not participate strongly in the study. However within topics of interest of using BIM for FM, practitioners show their interests in the use of BIM for existing buildings, real estate portfolio analysis, master planning and feasibility and integrating BIM with facilities management and operation software. Students reported that the development of a framework for continuing the flow of information in a coordinated/comprehensive manner, development of a method for updates and maintenance checks and the linkage of large manuals and important information with BIM were the top rated topics of interest.

A research priority is to determine and define the sets of data that are necessary for facilities management and post-occupancy operations that can be included in the contract documents. The study also identified the main barriers for implementing BIM for FM in which lack of software interoperability, resistance to fundamental change by institutions and lack of objective and scientific studies that quantify the value of BIM for FM were the main barriers for implementation.

Olatunji & Sher (2009) studied that BIM capabilities such as project visualization, behavior simulation, auto-alert and value intelligence can improve and provide a different approach from current conventional practices used in facilities management processes. Project visualization promotes project participants to effectively collaborate and analyze design intents and use of spaces. The representations of buildings components in 3D with photo-realistic presentations allow clients to visualize project information in a virtual environment as shown in Figure 7. They can visually evaluate multiple design alternatives to optimize, estimate and manage facilities.

Figure 7: Use of 3D-photorealistic representations – Courtesy of Tim Power, Aedas Architects

The advantages of using project visualization are not only important for architecture aspects of the design but also to visualize how the facility will operate. For instance, the Pantex Complex in Amarillo, Texas, started to use BIM to demonstrate to the operation staff how the building will work and be able to virtually walk-through the facility before construction started. Figure 8 shows the visualization of the Pantex Complex project. The participations of operations staff early in the design phase resulted in the detection of 500 serious problems. In the current conventional CAD environment it is not possible to provide this benefit (Young et al., 2009).

Figure 8: Visualization of operations in Pantex Complex, Amarillo, Texas. (Young et. al, 2009)

Simulation allows models to be analyzed predicting a real life situation. The use of simulation is recent but is evolving rapidly. Maher (2008) states that using simulation applications for predicting productivity and creativity in construction is increasing.

In FM simulation, simulation can predict end-users reactions to energy consumption, environmental impacts, response to emergencies and simulation of maintenance operations, thus reducing risk and uncertainties (Olatunji & Sher, 2009). Figure 9 illustrates the use of simulation to check clearance space for maintenance operations to avoid situations where space to perform maintenance operations is not sufficient as shown in Figure 10.

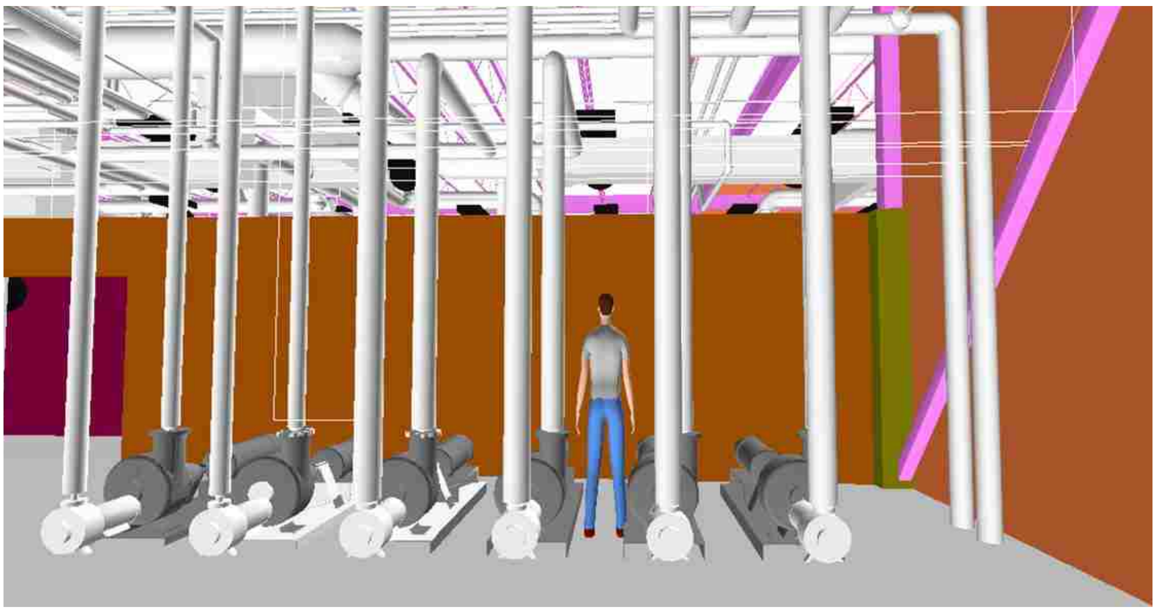

Figure 9: Using simulation for maintenance operations – Courtesy Birgitta Foster

Figure 10: O&M worker performing maintenance work with limited space – Courtesy Birgitta Foster

The Sidney Opera House is one of the few examples of creating a building information model for an existing facility (Figure 11). This project demonstrated benefits in digitizing design documentation and O&M manuals. The project established that BIM is “an appropriate beneficial technology enabling storage and retrieval of integrated building, maintenance and management data for Sydney Opera House” (CRC, 2008). The reported advantages were the consistency of data, intelligence in the model, 2D and 3D representations, an integrated source of information for existing applications, and integrated searchable databases. In a professional conference, Stuart Bull, BIM coordinator of the project recognized that it was the first time the owner and its consultants understood how the facility functioned (Smith & Tardif, 2009)

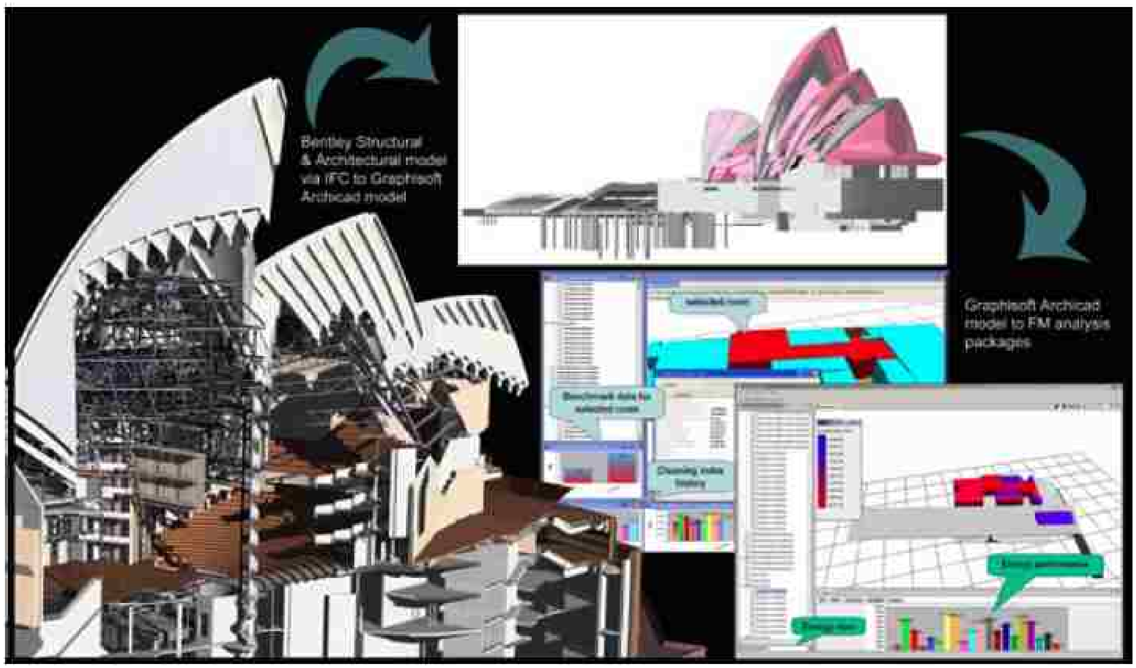

Figure 11: BIM model for the Sidney Opera House (CRC, 2008)

Rojas et al., (2009) evaluated different types of technologies used to capture as-built information based on productivity and economical analysis. The methods used were using (1) paper forms and computer data entry, (2) laptop computers, (3) digital pens, and (4) handheld computers. Hand-held ultra-mobile personal computer was most efficient method based on the conditions of the experiment. However, the relevant part of the study was to learn about the logistical issues, operational issues and user interface issues. Logistical issues include limitations to access facilities and to specific areas within those facilities as well as ensuring that field surveyors have all the necessary gear to perform their duties. Secondly, operational issues include the procedures followed by surveyors to capture information as well as the unavailability of updated drawings. Attribute data include those attributes required for proper maintenance and operations of facilities. Buildings may go through several renovations, as-builts are not normally updated and this can cause discrepancies in the survey process. Minimizing the amount of data and ensuring accuracy of the drawings are very important for the field survey planning process. Ultimately, user interface issues are related to the design of software application used to collect field data. In O&M, operational issues constitute one of the major barriers because unavailability of to access O&M information, the inaccuracy of as-built drawings and the lack of complete attribute data for equipment maintenance.

Akcamete, Akinci, & Garrett (2009) highlighted the importance of having up-to-date as-built information in making decisions in the O&M phase, where as-builts are almost never updated. Having historical data of repairs and maintenance is critical for building performance analysis and for life cycle analysis. Facility managers can make better decisions for proactive management, deterioration and emergency response. The study concluded that BIM is a useful tool to update as-builts. However, current BIM tools have limitations for detecting the history of changes over time.

2.3 Facilities Operations and Maintenance

2.3.1 Definition

Facilities O&M includes all the services required to guarantee that a constructed facility will function accordingly to the parameters for which was designed and constructed. "Operations" include the daily activities necessary to provide a safe and comfortable environment, whereas "Maintenance" prevents building systems and equipment to fail in order to perform their intended function. Operations and maintenance are used as a single term, O&M, because a facility needs to be maintained in order to operate efficiently (www.wbdg.org).

The Federal Energy Management Program (FEMP) defines O&M as " the decisions and actions regarding the control and upkeep of property and equipment. These are inclusive, but not limited to, the following: 1) actions focused on scheduling, procedures, and work/systems control and optimization; and 2) performance of routine, preventive, predictive, scheduled and unscheduled actions aimed at preventing equipment failure or decline with the goal of increasing efficiency, reliability, and safety" (Sullivan, Pugh, Melendez, & Hunt, 2004).

2.3.2 Importance of O&M

Operating and maintaining a facility effectively is "one of the most cost-effective methods for ensuring reliability, safety and energy efficiency" (Gallagher et al., 2004). The cost of malfunctioning mechanical, electrical, plumbing and fire protection equipment, water and air leaks, losses from steam and other losses can be significant to the owner.

Facilities are designed and constructed to be in service for decades, thus they need to go through periodic maintenance activities and repairs or replacement of equipment to upkeep its performance. Figure 12 illustrates a how a building's performance decreases, as is service during the years. The figure depicts how the useful life of the building would be reduced at a faster rate without proper maintenance compared to an optimized decrease rate with proper maintenance (Gallagher et al., 2004). Properly executed O&M guarantees that the equipment will work accordingly to its life expectancy, and in some cases go beyond it. On the other hand, the costs related to equipment failing early are not usually considered in the budget, thus they become an extra expense for the O&M activities (Sullivan et al., 2004).

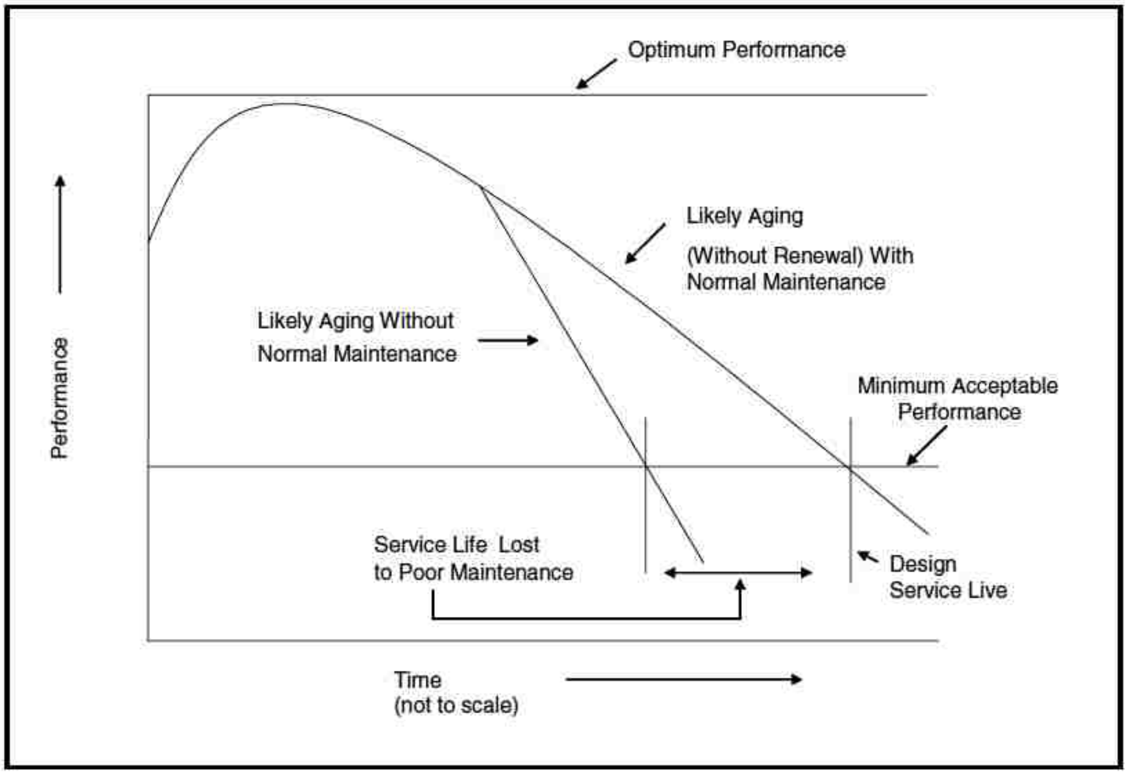

Figure 12: Maintenance Effect on Facility Performance (NRC, 1998)

The total cost of ownership includes all the expenditures an owner made or will make over the facility lifecycle (Gallagher et al., 2004). The O&M phase is the longest phase in a building lifecycle as shown in Figure 13. According to E. Teicholz (2004), more than 85% of the total costs of ownership are spent on O&M.

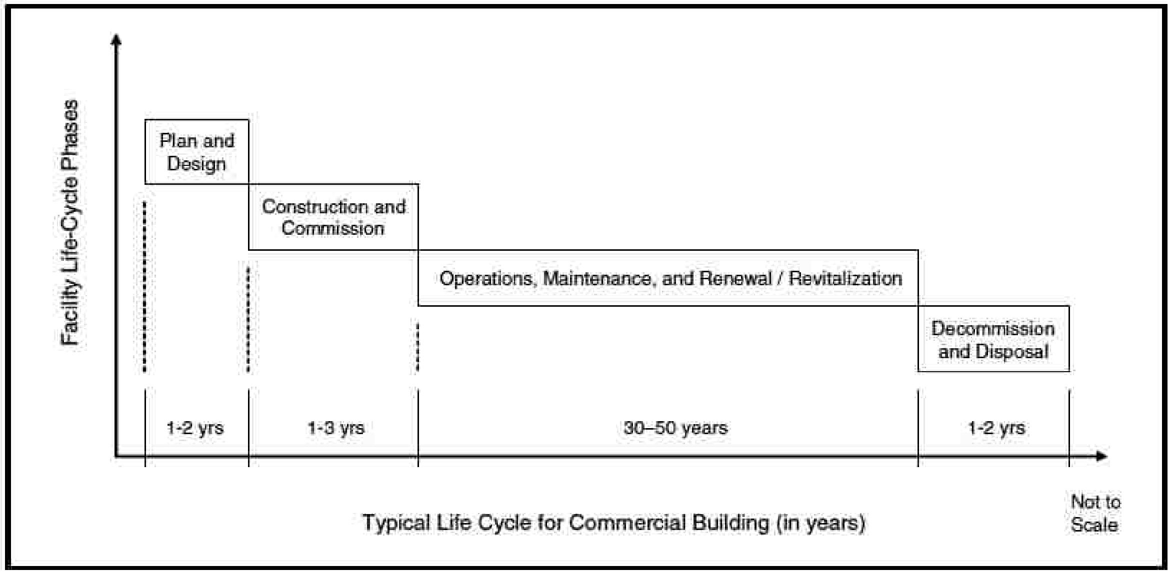

Figure 13: Facility Life-Cycle Phases (NRC, 1998)

The National Research Council (NRC, 1998) reported that the main reason public buildings are deteriorating at faster rate is the "failure to recognize the total cost of ownership". The failure to recognize the cost accumulated in the O&M phase results in faster deterioration, higher operating costs, decreases in energy efficiency, safety and health issues and overall reduced operating life of the building.

The U.S. Department of Energy Forrestal Building conducted a demonstration based on O&M-based energy efficiency with the purpose to track and meter the steam use in the building. In the study, they found that $250,000 was spent resulting from steam leaks. One of the key lessons learned was that many O&M deficiencies exist because building operators do not have proper information to evaluate their daily operations (Sullivan et al., 2004). Availability of data on facility systems is critical to make estimates about maintenance, repair, and renewal requirements during the remaining asset lifecycle. Inaccurate and poor information can prevent owners and planners to make the best decisions for their assets. Managing this data is extremely important to effectively provide the best possible services to the building owners and end-users (Gallagher et al., 2004).

Lee & Akin (2009) studied the inefficiencies in maintenance fieldwork by shadowing O&M tradesman for four weeks. Based on their observations, the study categorized inefficiency in two groups: structural and individual. Structural inefficiency is caused by the maintenance environment. For instance, locating equipment and getting information on materials, spare parts and tools. Individual inefficiency is caused by specific person that makes isolated mistakes; getting information on material, spare parts and tools is also part of individual inefficiency. Figure 14 illustrates the root cause of maintenance inefficiency derived from the study.

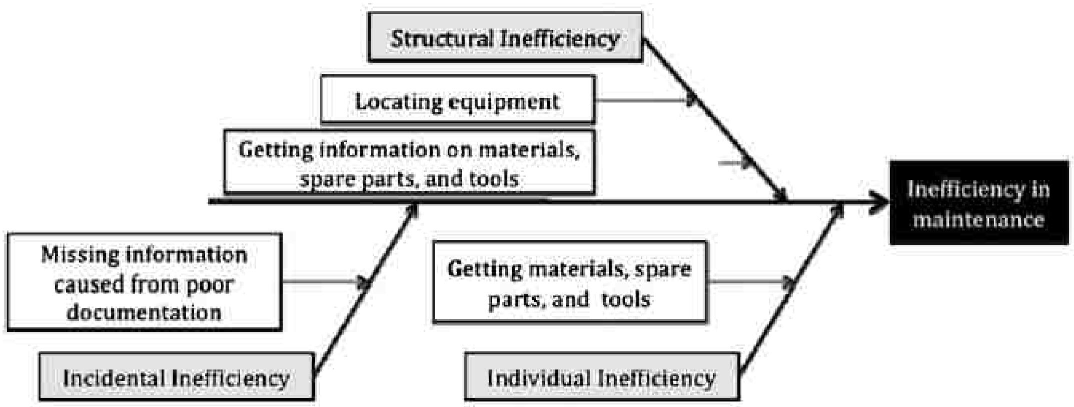

Figure 14: Root-cause diagram of inefficiency in maintenance

The study stated that the causes presented in the diagram are mainly because of lack of available maintenance information. Locating equipment and facilities is the maintenance activity that causes significant delay and could save 6% of the total time with proper information. Even though, the time spent in documenting maintenance activities is not significant it is critical to maintenance history of the equipment. The study concludes that there is a 12% potential for improvement in maintenance efficiency with using digital technologies and computational support. Taking in consideration transit time the potential improvements on efficiency could reach 21%.

2.3.3 Types of Maintenance

The type of maintenance programs can be classified in different ways. The FEMP defines four categories:

- Reactive Maintenance: "Reactive maintenance is basically "run until breaks mode". No actions or efforts are taken to maintain the equipment as the designer originally intended to ensure design life is reached."
- Preventive Maintenance: "Actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level."
- Predictive Maintenance: "Measurements that detect the onset of a degradation mechanism, thereby allowing causal stressors to be eliminated or controlled prior to any significant deterioration in the component physical state."
- Reliability Centered Maintenance: "A process used to determine the maintenance requirements of any physical asset in its operating context."

Piotrowski (2001) breaks down maintenance programs and their costs as follows:

Table 1: Percentage Breakdown of Maintenance Program and Cost

Maintenance Program	Percentage	Cost
Reactive	More than 55%	$18/hp/year
Preventive	31%	$13/hp/year
Predictive	18%	$9/hp/year
Other	2%	$6/hp/year

According to this study, the majority of maintenance resources and activities applied to an average facility are still reactive.

(E. Teicholz, 2001) categorized three areas for maintenance programs:

- "Demand work: where the client calls in for service, where breakdowns in equipment require repairs and emergency events that affect the facilities department."
- "Preventive maintenance work: where a scheduled program of work maintains the investment in the physical assets for a corporation. These assets may be equipment assets or facility assets."
- "Project work: where changes to the business focus require a reorientation of space and people or the changes in regulations require upgrades to maintain compliance, such as ADA, EPA, or OSHA." ADA, EPA, and OSHA stand for Americans with Disabilities Act, Environmental Protection Agency, and Occupational Safety and Health Administration."

2.3.4 Work Orders

Work orders are defined as "a set of tasks necessary for the maintenance and/or repair of assets throughout the life-cycle of that asset and are critical elements of maintenance management". Work orders may be scheduled to the regular maintenance of the asset and unscheduled to events that damage the asset (www.doi.gov).

Figure 15 shows a standard work order flow diagram for any type of facility. Most institutions use a Computerized Maintenance Management System (CMMS) to track and generate work orders by equipment or component. A CMMS tracks historically all works orders, scheduled and unscheduled, stores maintenance procedures and warranty information, O&M manuals, as well as other technical documentation. The main advantage of CMMS is the elimination of paper work and manual tracking of activities. CMMS is the database for all maintenance activities and equipment. Even though there are major proven benefits to manage O&M activities, CMMS are not used to its full capabilities because of the time consuming process to insert O&M information into the system. Figure 16 and Figure 17 illustrate the use of CMMS used at UNM.

Work Order Flow Diagram

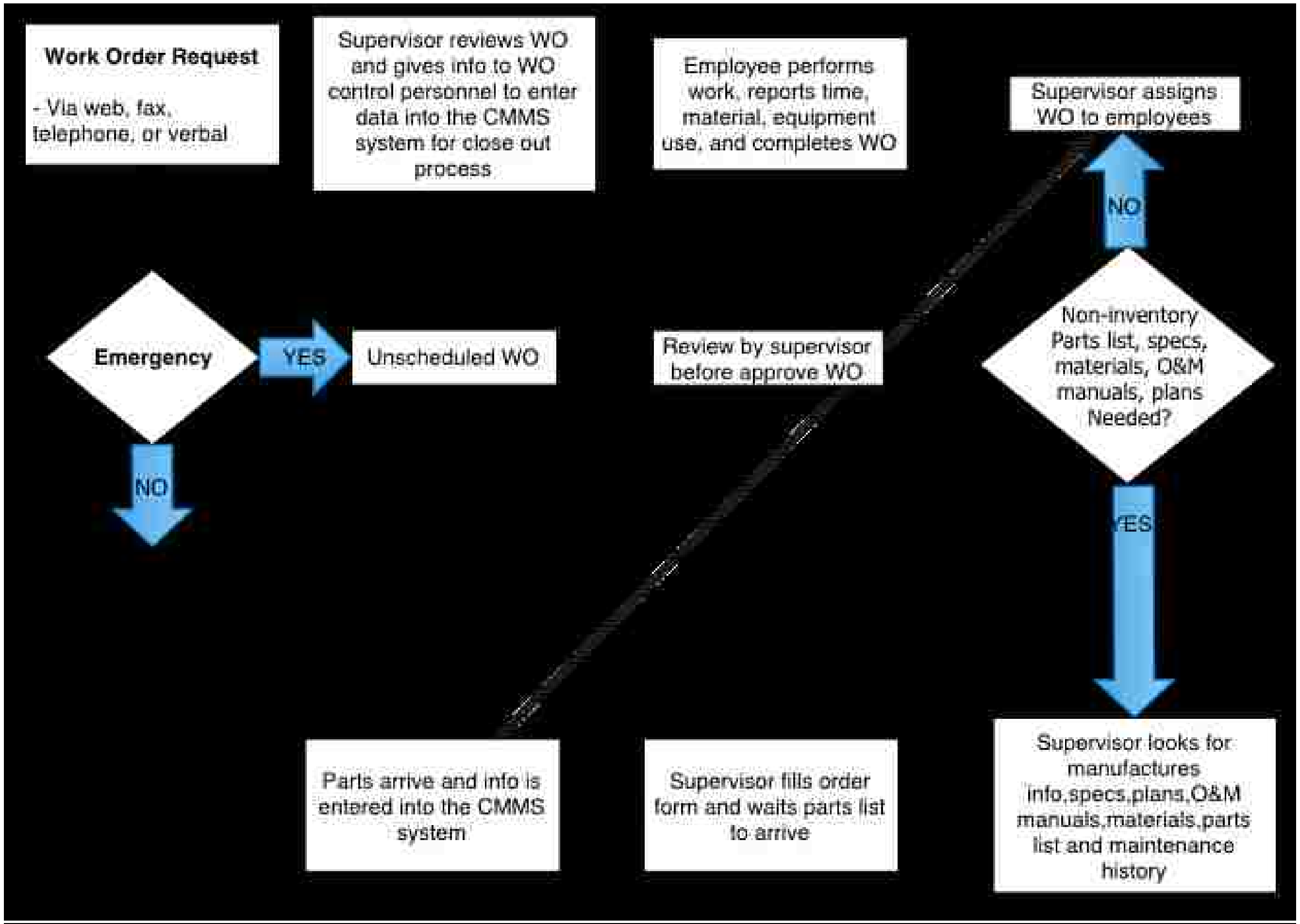

Figure 15: Work Order Flow Diagram

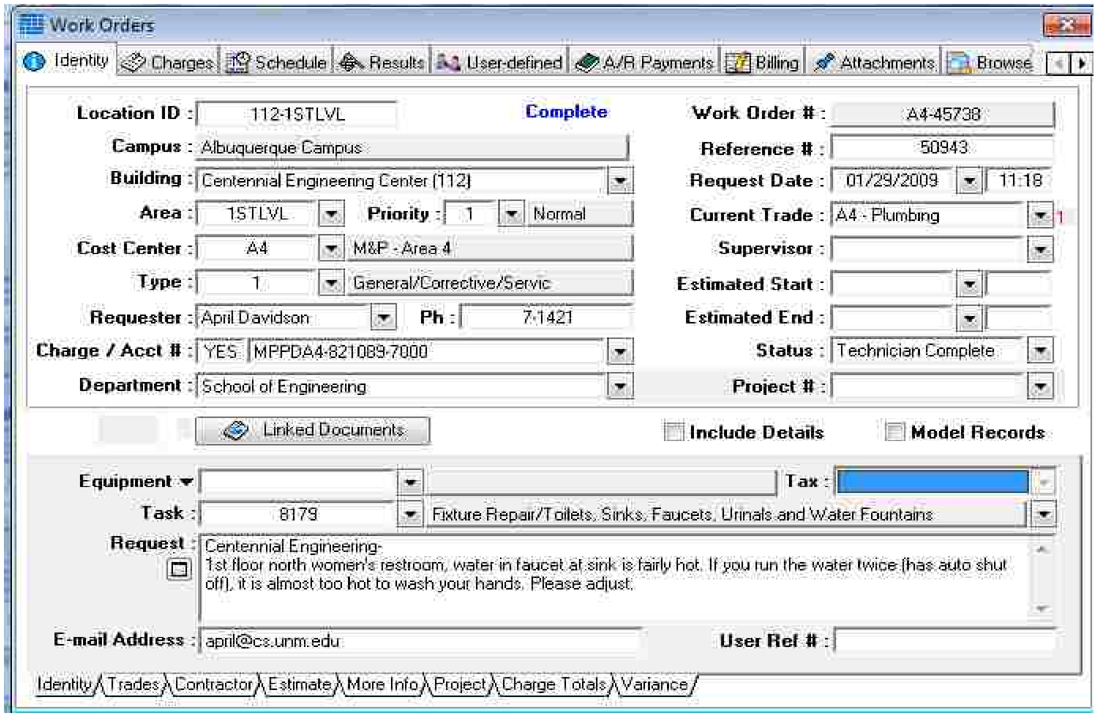

Figure 16: CMMS used at UNM to track Work Orders

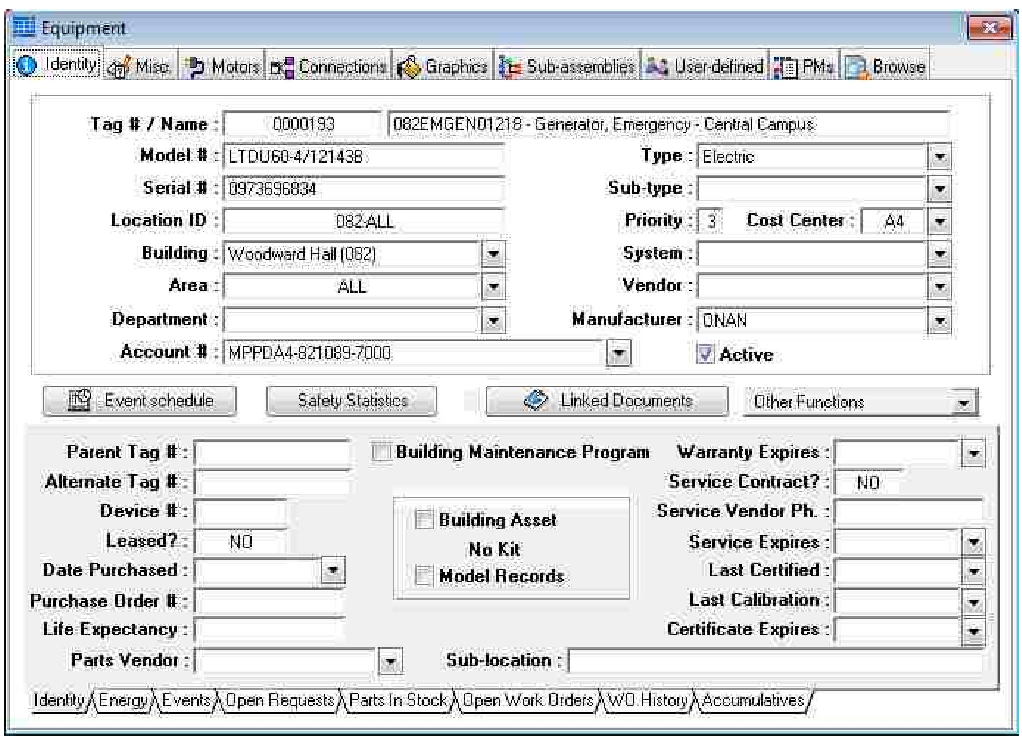

Figure 17: CMMS used at UNM to track equipment history

2.3 Interoperability

The term “interoperability” used in this thesis has a broader meaning from the traditional concept commonly known as the ability to exchange data seamlessly between software applications. The National Institute of Standards and Technology (NIST) defined interoperability 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” (Gallagher et al., 2004).

2.3.1 NIST Study

In 2004, NIST reported an estimated efficiency loss of $15.8 billion per year resulting from inadequate interoperability in capital facilities. The main motivation of the NIST study was to assess the inefficiencies in the exchange and management of information between project participants, but also reveal the opportunities in the use of information technologies in a building lifecycle. The study included commercial, industrial and institutional buildings and focused on construction taking place in 2002, in which 105 individuals from 70 organizations representing all the stakeholders in the industry (architects and engineers, general contractors, specialty fabricators and suppliers, and owners and operators) were surveyed and interviewed. The cost of inadequate interoperability was calculated by comparing current practices with ideal situations in which there the information flow was seamless and non-redundant.

The results showed that inadequate interoperability accounted for an increase of $0.23 per square foot per year for O&M of existing facilities. Of the estimated $15.8 billion losses from process inefficiencies, owners and operators incurred approximately $10.6 billion (67%), architects and engineers were responsible for $1.2 billion (8%), general contractors for $1.8 billion (11%), and specialty fabricators and suppliers for $2.2 billion (14%). Figure 18 shows the percentage breakdown of these costs incurred by stakeholder group. The O&M phase has the highest cost of $9.1 billion followed by the construction phase with $4.1 billion and finally, the planning, design, and engineering phase with $2.6 billion. The $10.6 billion efficiency loss absorbed with owners and operators was attributed to the use redundant information technology systems, time-consuming information verification and validation, inefficient business process management, and costly information delay to employees waiting for the necessary information to resolve a maintenance issue (Gallagher et al., 2004).

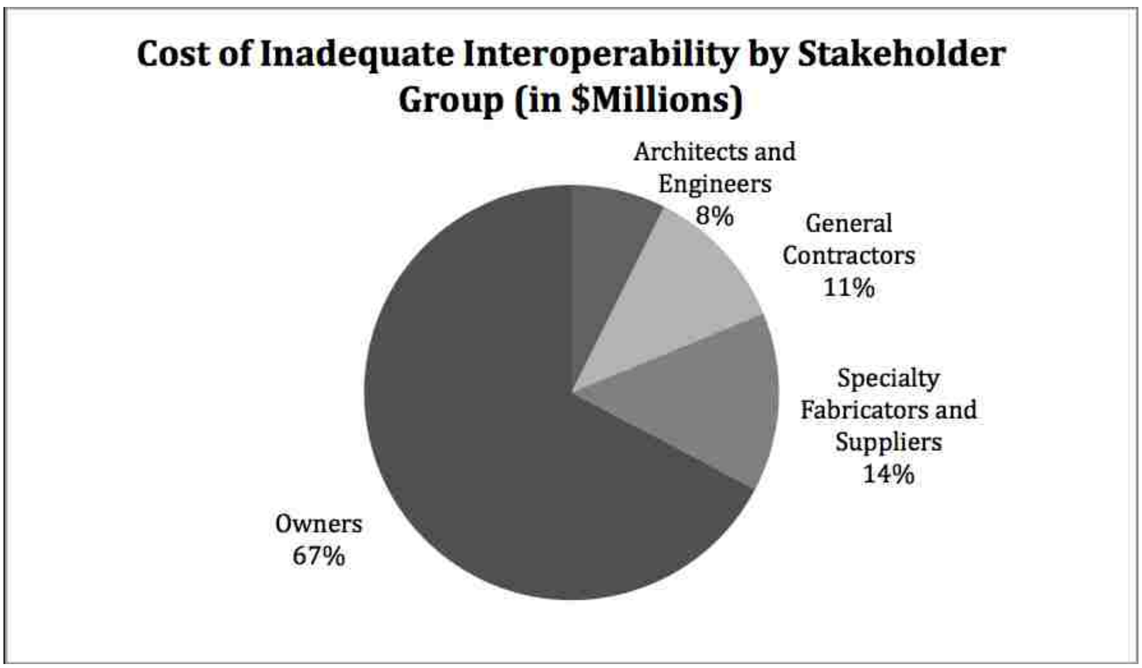

Figure 18: Cost of Inadequate Interoperability by Stakeholder Group (NIST, 2004)

Figure 19 illustrates the four main phases in a facility lifecycle. During these phases a vast amount of information is created and transfer from one phase to other. As the project moves forward, the amount information increases, however with the current conventional practices it has been difficult to transfer that information especially from the construction phase to the operations phase. In the graph, the doted line represents the As-Is condition and how information is continuously lost when from phase to phase. The value of information is significantly reduced due to the handoff information that is not consistently transferred from one phase to the other. The solid line illustrates the To-Be condition with the use of BIM that collects data continuously throughout facility life-cycle; thus data loss is minimized and the value of information is maximized.

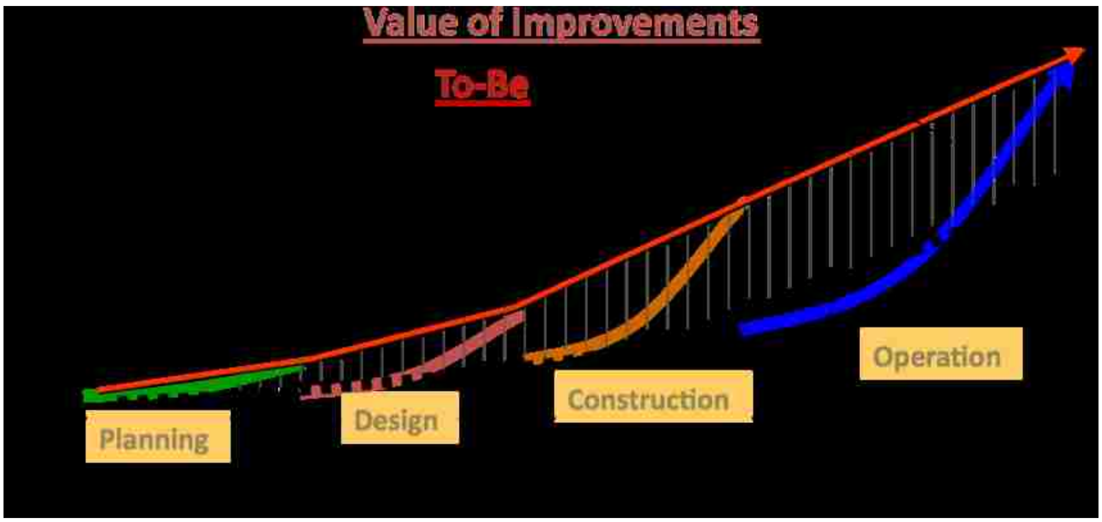

Figure 19:Data Losses in the Building Life Cycle (Smith & Tardif, 2009)

2.3.2 Sandia National Laboratories Study

At Sandia National Labs, BIM expert used the " View the Future for FM" video with an in-house planner survey to validate the results from the NIST report. From this study, O&M personnel at Sandia Labs estimated that they could save up to 2 hours per work order. Sandia performs 24,000 work orders per year and the average wage salary of O&M personnel is $50 per hour. Based on this information Sandia National Labs estimated that could save $2.4 million per year. This number is significant considering that the annual budget of Sandia National Labs is $ 14 million (B.Foster, 2010).

2.3.3 FIATECH Approach

FIATECH is an industry consortium of owners, engineers, construction contractors and technology suppliers that promotes the development and use of technologies to improve all phases in the lifecycle of capital projects and facilities. According to FIATECH, some of the major problems related to systems information interoperability in the construction industry are (paraphrased):

- The difficulty to retrieve accurate data, information, and knowledge efficiently in every phase of the construction project lifecycle.
- A lack of interoperability between systems, with different types of standards created to manage data. A common process for managing construction project information does not exists.
- Lifecycle problems are not given the necessary importance and therefore modeling and planning do not considered all lifecycle aspects. Operation, maintenance, environment impact, and commissioning issues are given minor consideration when planning a project.
- The limitations of available tools and lack of knowledge do not have ability to assess uncertainties, risks, and the impact of failures.

To address these issues, FIATECH has created a roadmap to integrate all functions of a facility planning and management systems and all required information in a integrated facility management environment (Figure 20).

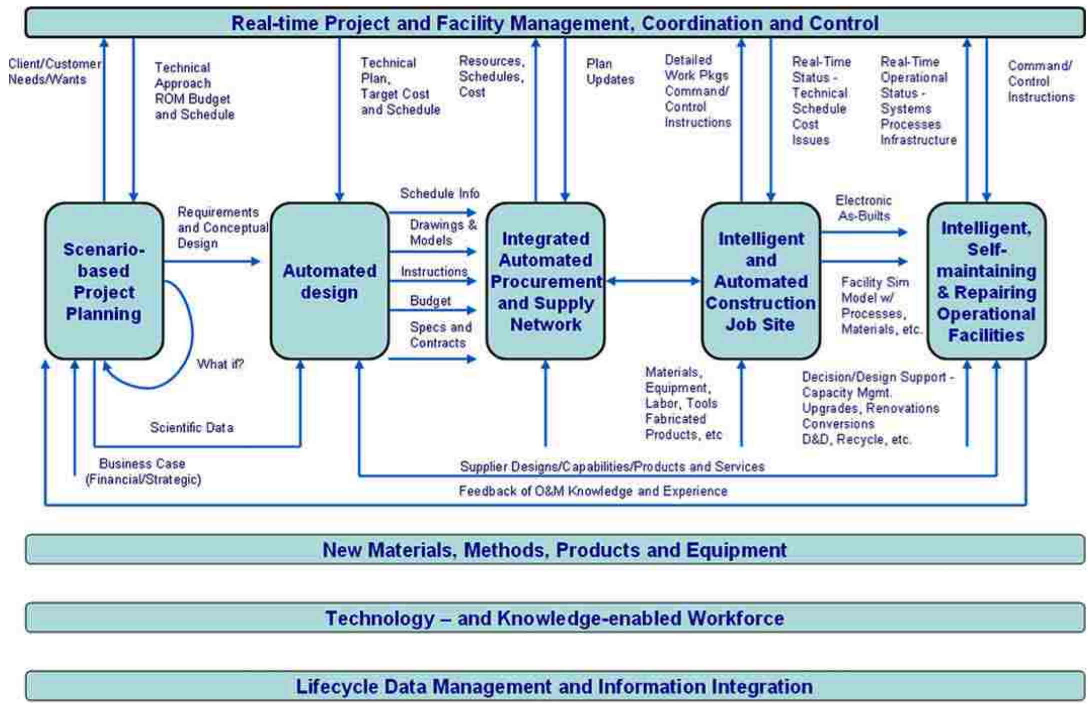

Figure 20: FIATECH-CPTR Vision (www.fiatech.org)

As seen in this chapter, inefficiencies in information exchange are significantly costly and mostly absorbed by the owner during the O&M phase. The O&M phase is the largest and costliest phase in a building lifecycle. It is very important to maintain a building periodically to guarantee that it will perform accordingly with its intended purpose and ensure the safety of its occupants. Current conventional practices to operate and maintain buildings are highly inefficient where information is inconsistent and lost in the project phases. BIM has proven many benefits in design and construction phases, however it is necessary to look beyond these two phases and extend the benefits to the O&M phase. Building Information Models are databases able to exchange structured information in a formal, consistent, and organized way. BIM can collect data continuously during the building lifecycle in order to reduce the information gaps that have been adding extra costs to the owner.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

As stated before, the concept of using BIM for O&M is relatively recent, the most appropriate approach to determine the perceived value of using BIM for facilities O&M is to employ a mixed methodology and conduct the research in two phases.

The first phase of the research included an extensive review of the related literature followed by in depth interviews with O&M professionals. Based on the information obtained from the first phase, the second phase was to develop an online survey to be distributed to facilities operations personnel across the US. The survey included a video demonstration titled "View of the Future for FM", that illustrates what could be the future use of BIM in O&M. Figure 21 represents the research methodology.

Figure 21: Research Methodology

3.2 Perceived Value

In the last two decades, perceived value studies have been widely used by marketing researchers in academia and industry. However, the concept of "value" has not been clearly defined yet (Sánchez-Fernández & Iniesta-Bonillo, 2009). (Zeithaml, 1988) defined it as "…the customer's overall assessment of the utility of a product based on the perceptions of what is received and what is given". On the other hand, many researchers argued that definition represents a narrow approach and that other variables must be considered that can also provide value. As a result, many authors like B. J. Babin & L. Babin, (2001); Holbrook (2006); Mathwick, Malhotra, & Rigdon, (2001) described "perceived value" as complex, multifaceted, dynamic and subjective.

Le Clerk and Schmitt (1999) observed"…time is perceived as having value and as capable of being of bought and spent as well as being saved and wasted". Time and convenience have increasing importance among clients and many authors have acknowledge that time should be viewed as critical variable in any assessment of value (Heinonen, 2004); (Holbrook, 1999); Zeithaml, (1988). In the present research perceived value will be determine based on time savings from the use of BIM can provide to O&M workers.

3.3 Research Questions

Conventional practices and inefficiencies to access relevant O&M information are major issues in the upkeep of facilities for their intended purpose. There is a great opportunity to use BIM as a tool to overcome these issues. The nature of BIM as a structured repository of information can facilitate the access to information and resolve many issues that are encountered in operating and maintaining a facility. For that matter, in order to determine the perceived value of using BIM for O&M in order to save time, the following questions are posed for the research:

- How often would facilities operations personnel use BIM to access O&M information?
- What percentage of time could facilities operations personnel save in the work order process by using BIM?
- What effect would BIM have in the response time to unscheduled work orders?
- What are the potential benefits of using BIM for O&M?

Secondly, this research expects to obtain information about the following topics:

- Explore current O&M practices
- Rating of current accessibility to O&M information and accuracy of as-built drawings
- Assess the facilities operations personnel familiarity with BIM.

The intent is to determine the perceived value and future benefits of using BIM as a way to visualize and access valuable O&M information in order to encourage owner's implementation of BIM.

3.4 Research Approach

3.4.1 Literature Review

The review of the related literature (Chapter 2) was the first step to obtain information about previous related studies. The extensive literature review included books, peer reviewed journal articles, reports, white papers, manuals, case studies, web seminars, presentations and websites related to the study. The literature review provided theoretical background in the following areas:

- Building Information Modeling
- Operations and Maintenance
- Interoperability

The literature has numerous articles related to building information modeling. Most of these articles are focused on the uses of BIM in the design and construction phase of a project. Some studies focused on enhancing interoperability between BIM software applications and other studies related to developing collaboration frameworks and BIM standards. There are very few articles that study the use of BIM after construction. O&M is a topic with a lack of interest for most researchers even though it is the largest and costliest phase of a project's lifecycle. Most of the literature reviewed was based on books, manuals and best practices. Studies on interoperability are mostly focused on the exchange of data seamlessly between software applications. Few reports studied interoperability from the standpoint of managing and communicating data between project participants.

In addition, the literature review helped to identify areas that have not been covered in previous studies and how this study can expand on those areas. Finally, it provided knowledge about the topic being studied and helped to clarify and refine the research questions and methodology.

3.4.2 Interviews

The first phase of the research also included semi-structured interviews (Oppenheim, 1992) with people performing activities directly related to O&M of facilities. The interview was determined to be the right method to obtain detailed background information about the O&M procedures, the work order process, and the issues incurred when dealing with O&M information. The first step of the interview process was to identify key participants performing different roles in O&M activities. The purpose was to learn about the work they perform but also to obtain different perspectives about their current issues with O&M information. The second step was to develop the interview schedule that asked the following open-ended questions:

1) What is the most important O&M information needed after the completion of a project?

2) How would you rate the accessibility and accuracy of this type of information?

3) What are the most commonly found issues in dealing with O&M information?

4) What information would you like to access in a single place that would improve your daily work?

Even though, the interviews included an interview schedule, they remained flexible and other questions were formulated as they came to mind based on the topic being discussed. Open-ended questions were more appropriate in order to obtain in-depth information. The third step was to conduct the personal interview. The interviews were conducted on four professionals with experience in operating and maintaining facilities in the Physical Plant Department (PPD) at the University of New Mexico (UNM). One additional interview was conducted with a representative of a local private corporation.

All interviews were conducted face-to-face at the interviewee's office with an approximate duration of 1-1.5 hours. Handwritten notes were employed to record the information gathered in the interviews. The quality of interaction was satisfactory in all cases which guarantees the information obtained. In two cases interviewees demonstrated their high interest in the subject, and a local BIM expert performed two informative presentations to their O&M groups on the topic of BIM for Facility Management followed by a discussion session. These group presentations were useful to encourage participant's participation in the follow-up online survey. All of the interviewees were willing to be contacted for further information and also they were willing to test the survey before it was broadly distributed.

3.4.3 Online Survey

The literature review and interviews were the basis to develop the questions for the online questionnaire. An online survey was determined to be most cost effective method to collect data from respondents located in different geographical areas. Online tools also facilitated the distribution of a video, which was a critical part of the survey. The intended audience for the survey was people involved with O&M activities in different types of facilities across the country such as: O&M directors, O&M planners, facility managers, facility engineers, and craftsman/tradesman. The survey consisted of a total of 25 questions divided in two parts. The first part contained four sections: 1) General Information, 2) Facility Description, 3) Operations and Maintenance, and 4) Building Information Modeling. The second part showed a short video titled "View of the future for FM" followed by a set of questions that would determine the perceived value of using BIM for O&M. A list of survey questions is included in Appendix 1.

The survey was designed to be completed in approximately ten minutes including the video demonstration. Most of the questions have structured response categories but the survey also included some open-ended questions. Some of the questions were mandatory in order to obtain the necessary information to assess the value of BIM for O&M. Most of the response categories also included an "Other. Please Specify" option.

The questions were created using basic guidelines provided by the literature (Kumar, 2005). For instance:

- Use of simple and everyday language
- Do not use ambiguous language
- Do not ask double-barreled questions
- Do not ask leading questions
- Do not ask questions based on presumptions.

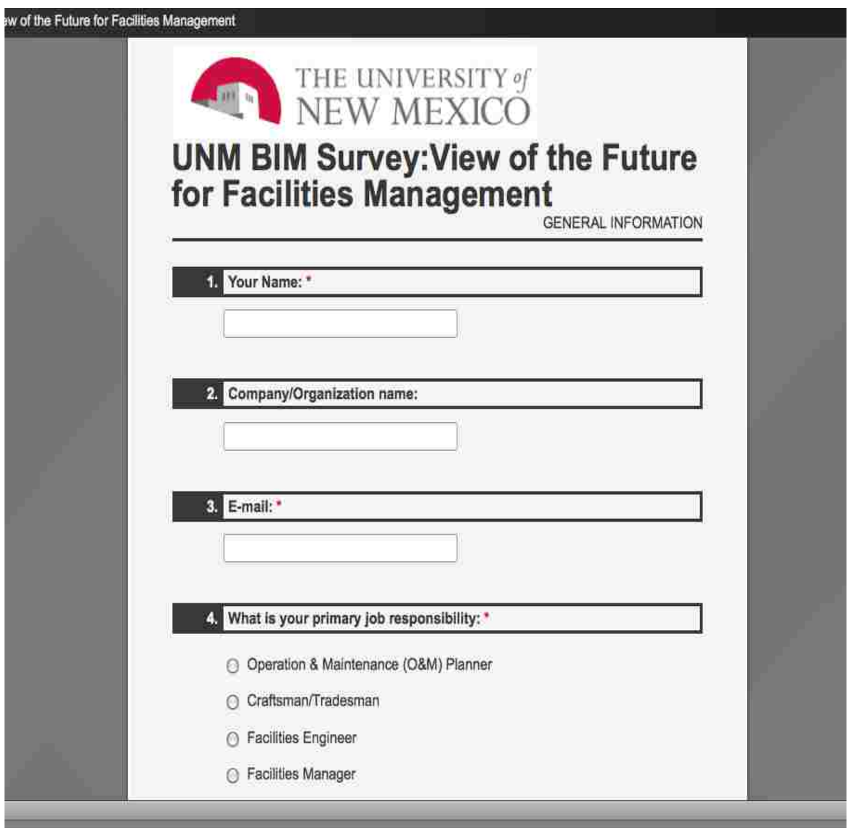

Figure 22: First Page of the Online Questionnaire

The order of the questions followed a logical progression based on the objectives of the study and design of the survey. Once the questions were defined, they were entered into online survey software and linked through the BIMWorkx website (Figure 22). The survey was electronically distributed through professional organizations, software vendors, web seminars, websites, blogs and forums. It included a cover letter (Figure 23) that introduced the researcher and the researcher's institution, a brief description of the objectives of the project, a brief description of the survey questions, the importance of the study and contact information for the researcher for comments and questions. Moreover, the cover letter assured the anonymity of the respondents and the information provided by them.

UNM BIM Survey : "View of the future for Facilities Management"

THE UNIVERSITY of NEW MEXICO

Francisco Forns-Samso, graduate student in the Construction Program at the University of New Mexico(UNM), in collaboration with BIMWorkx, are conducting a research study in the area of Building Information Modeling (BIM) for Facilities Management (FM). The intent of this study is to determine the perceived value and future benefits of using BIM as portal to visualize and access important Operation and Maintenance (O&M) information. The survey consists of a two (2) part questionnaire : initial set questions on your facility characteristics and how you currently perform O&M activities and a follow on set of questions after watching a short "View of the Future for FM" video. To complete survey including watching the video should take about 5 minutes.

The results of this research will be published and distributed upon request to those who are interested.

Please note that your name and that of your facility will not be identified with any of the results.

If you have any questions or comments please do not hesitate to contact :

Francisco Forns-Samso, Graduate Student.

University of New Mexico

Department of Civil Engineering

Construction Program

505-340-8471

Figure 23: Cover letter of introducing the survey

3.4.4 View of the Future Video

The video titled " View of the Future for FM" was a very unique and important component in this study. The video shows a hypothetical scenario were there is a possible leak in a pump in building 720. In the CMMS system, in this case Maximo, there is a picture of the pump that when is selected it will take the user into the model were the pump to be repaired is located. Once in the model, the user can select the pump and a menu will appear with access to the O&M manuals, specifications, performance data, parts list, panel schedule, laser scan and CMMS system. Figure 24 shows a screenshot when accessing the O&M manuals through the model.

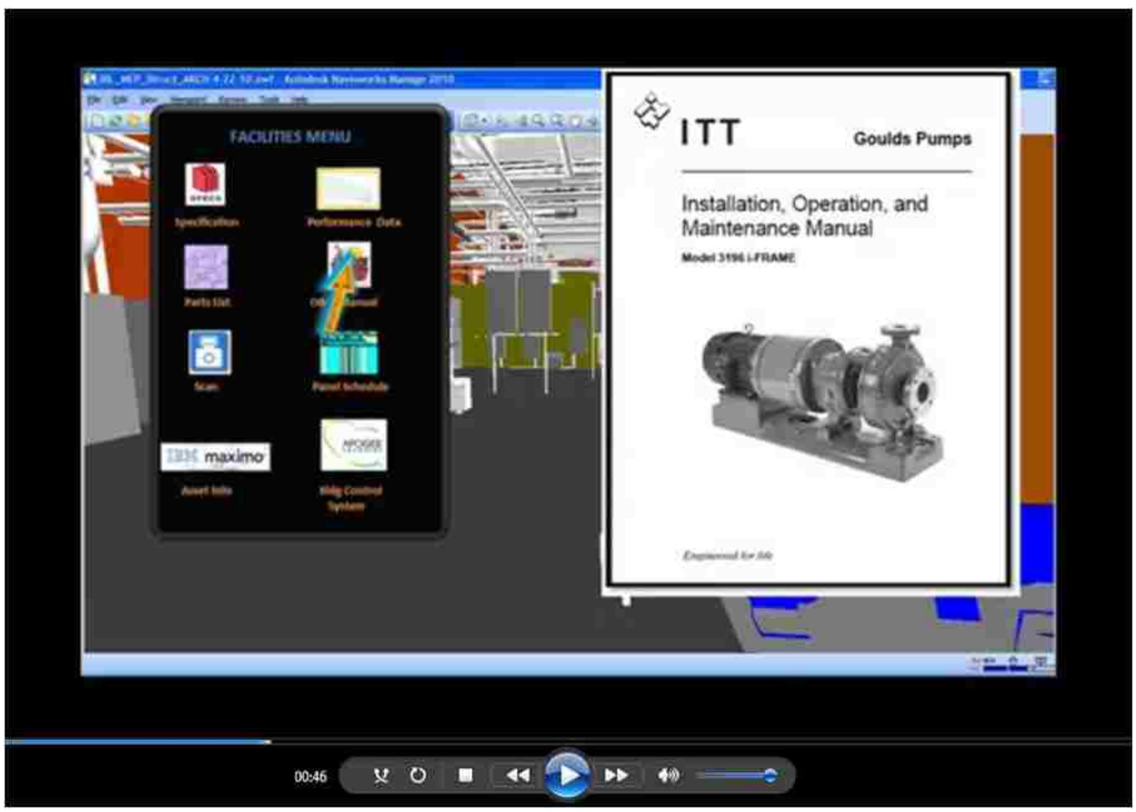

Figure 24:View of the future video screenshot

The use of the video was critical to demonstrate how in a near future the use of BIM can integrate important O&M information and work as a single source to access and maintain information. The main advantage of using the video was to reach an audience that was unfamiliar or vaguely familiar with the concepts of BIM, capture their responses to see if it has value to them. In addition, compare their answers with the ones from respondents that are more familiar with BIM. On the other hand, the use of video could have optimistically biased the audience because it demonstrate a hypothetical scenario were the access to information is seamless, scenario that is not possible at the moment.

3.5 Validity and Reliability

The online survey was the research instrument selected to answer the research questions. In order to gather data that is meaningful, the research instrument must meet certain criteria. Validity and reliability are parameters necessary to test the quality of data obtained from the survey. Validity is defined as "the ability of an instrument to measure what is designed to measure" (Kumar, 2005). Face validity is a validity test that measures validity based upon a logical link between the questions and the objectives of the study. Content validity is another type of assessment that test what the instrument is measuring what is supposed to measure based on the opinions of a group of experts in the field. It presents a systematic review of the survey to make sure that it included everything that should or should not be part of the survey. According to Kitchenham, content validity is subjective and is not a scientific measure of validity of a research instrument, but it provides a good basis for a rigorous study of validity (Kitchenham et al., 2002). Furthermore, it is the only form of preliminary validation in an area that has not been researched previously. This study employed face validity and content validity. Structuring questions that had a direct link with the purpose of this study was the best way to face validity. Content validity was tested by collecting responses from group of 5 experts that were selected by being a representative sample of the intended audience. This group of experts reviewed the survey questions and provided their comments on what should be included or deleted from the survey design. They provided their feedback if the content of the questions were in directly related with the purpose of the study. Furthermore, experts examined the questions for bias, clarity sequence and other parameters in a pilot study.

Reliability measures if the research tool is consistent, stable, predictable and accurate (Kumar, 2005). It determines if a research instrument will provide the similar results under the same conditions. Test/re-test is a common method for establishing reliability of the research instrument. In a test/re-test assessment the survey is administered once and then again under the same similar conditions. If the correlation between the first set of answers and second set of answers is greater than 0.7 the test/re-test reliability is good. For instance, a correlation value of 1 represents that respondent selected the same answers on the second testing as it did on the first testing.

This research conducted the test-retest to five experts to test the reliability of the study. The first and second testing were conducted one week apart in time. Table 2 shows the test-retest values provided by experts, the average correlation value of the five respondents was 0.8 that supports the reliability of the research instrument. However, having the same experts that supported the content validity and perform the test/retest can an influence on a higher correlation value. These people are already familiarized with the questions therefore their answer could be more predictable than performing the test retest to a random group of people.

Table 2: Test/Retest Correlation Values

Respondent	Correlation Value
Expert 1	0.84
Expert 2	0.8
Expert 3	0.76
Expert 4	0.88
Expert 5	0.72
Average =	0.8

3.6 Data Analysis

After the data collection was completed, the results of the survey were exported to Microsoft Excel for further analysis. Partial responses were not considered in the analysis and also responses from people not directly related to O&M work. The summary of the results of the survey is shown in Chapter 4 (survey summary) and Chapter 5 (data analysis). All questions were described and tested using a frequency graphs approach for incorrect ranges and unusual responses, and the survey responses were double checked for accuracy.

The data analysis therefore uses Pearson Chi-Square to test relationships and descriptive analysis calculating mean and standard deviation. It is important to demonstrate certain relationships that would predict the future use of BIM in O&M.

3.6.1 Pearson Chi-Square Test

The Pearson Chi-Square test is a nonparametric statistical technique used to analyze nominal or ordinal variables each with two or more categories. It tests to see if there is a relationship between theses variables, thus instead of using means and variances, the test uses frequencies or percentages. The chi-square test was selected as the most appropriate statistical technique to test relationship because of the nature of the survey that employed categorical responses. Fisher exact test is other alternative to Pearson Chi Square test but it only works for 2x2 tables. Chapter 5 also provides the values for the Fisher exact test to verify results. One of the key requirements of the chi square test is that the data categories are independent and mutually exclusive. The chi-square (χ^2) distribution is calculated by measuring the degree of deviation between observed (O) and expected (E) frequencies following the next equation:

$$\chi^2 = \sum[(O - E)^2 / E]$$

In order to perform the Chi-square test it is necessary that expected frequency be greater than 5.

CHAPTER 4 SURVEY SUMMARY

4.1 Overview

The first draft of the survey was completed on June 9th, 2010. The survey was pilot tested by industry experts from June 10th 2010 through June 19th 2010. After the survey was revised, it was distributed through professional organizations, websites, forums, blogs, seminars, presentations and web seminars from June 21, 2010 through July 25, 2010. The survey obtained a total of 125 completed responses, 99% of the responses were completed in the US (Figure 25).

Figure 25: Geographical location of respondents

Most of the responses were collected in the Southwest region with 38%, followed by the West with 18%, the Midwest with 16%, Southeast with 14% and the Northeast with 13% (Figure 26). The regions were divided as follows and contained the following states.

West Region: Idaho, Montana, Wyoming, Utah, Colorado, Alaska, Washington, Oregon, California and Hawaii.

Southwest Region: Arizona, Oklahoma, New Mexico and Texas.

Midwest Region: Wisconsin, Minnesota, Illinois, Indiana, Ohio, Missouri, North Dakota, South Dakota, Nebraska, Kansas, Michigan and Iowa.

South Region: District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida, Kentucky, Tennessee, Mississippi, Alabama, Arkansas and Louisiana.

Northeast Region: Maine, New Hampshire, Vermont, Maryland, Rhode Island, Connecticut, New York, Pennsylvania, New Jersey, Massachusetts and Delaware.

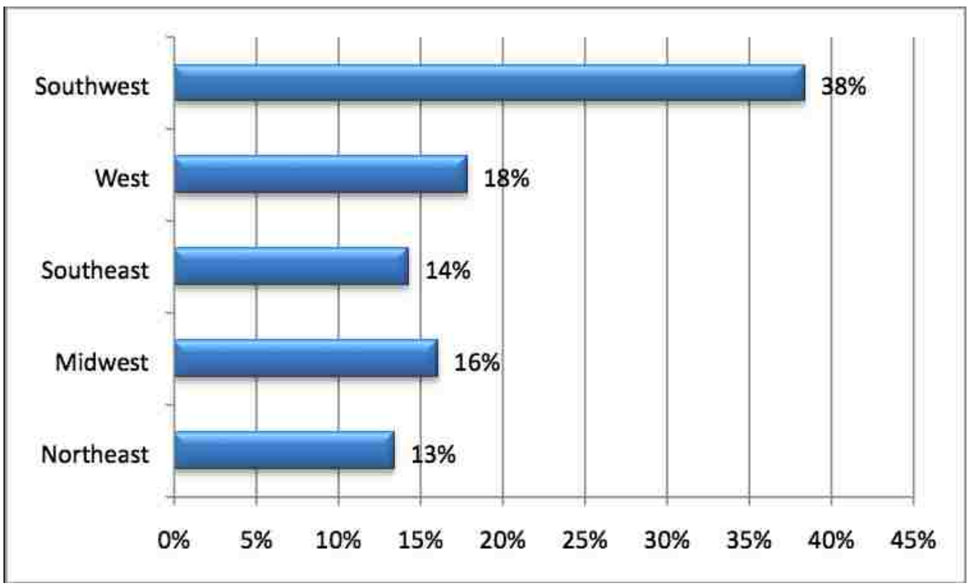

Figure 26: Geographical location of responses by region

The survey obtained 125 completed responses from O&M workers from different types of facilities. These people included O&M directors, facility managers, facility engineers, O&M planners, craftsman/tradesman, BIM managers, maintenance supervisors, architects and project managers. The data excluded partial responses and responses from people that are not directly related with facilities operations.

The survey consisted of a total of 25 questions divided in two parts. The first part contained four sections: 1) General Information, 2) Facility Description, 3) Operations and Maintenance, and 4) Building Information Modeling. The second part included a short video titled "View of the future for FM" followed by a set of questions that would determine the perceived value of using BIM for O&M

4.2 Facility Characteristics

All of the respondents were asked to choose one option from a list of possible answers of what best describes their facility, 68 respondents (54% of total) described their facilities as a campus with multiple buildings, 18% of the respondents described as individual buildings in multiple locations, 12% described one building in a single location, 9% described their facilities as multiple campuses with multiple buildings and 6% described them as other type of facilities (Figure 27). The category campus with multiple buildings mainly represents educational institutions such as universities, community colleges, public school and also government institutions. The category individual buildings in multiple locations includes banks, insurance companies, industries and hospitals.

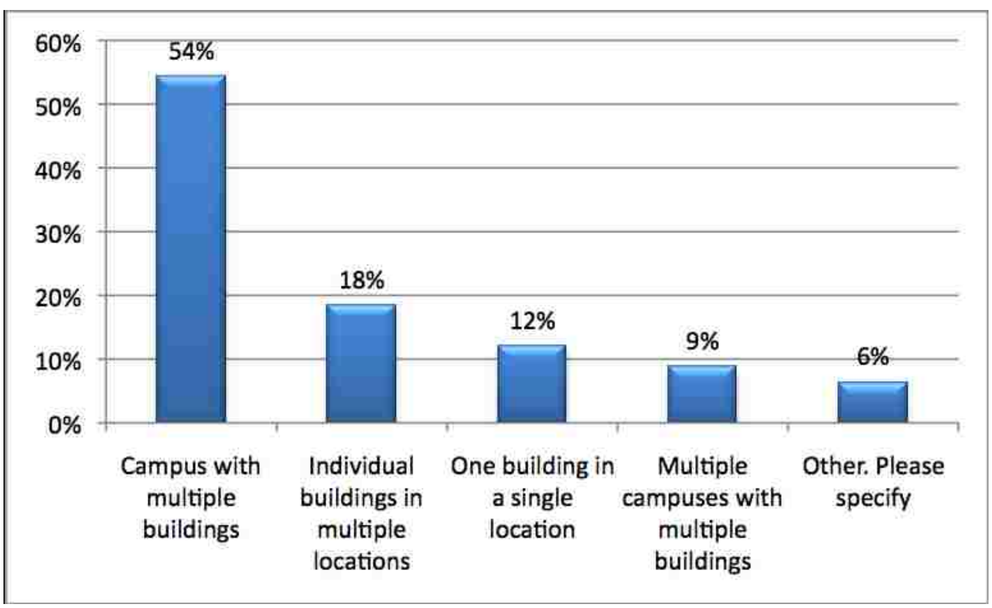

Figure 27: Description of facilities

The next question asked respondents to choose the primary use of their facilities. Respondents were allowed to choose more than one option from a list of possible choices that represented the use of their facilities. Thirty percent of the facilities represented educational buildings, followed by office (22%), government (18%), laboratory (15%), healthcare (9%), industrial manufacturing (5%) and retail (1%) (Figure 28). The "other" category that is 9% included other types of facilities such as religious, dormitories and aerospace facilities. The next question asked respondents to choose the size of the facilities respondents manage between multiple answers. Thirty-four percent of the participants in this survey manage facilities over 5 million square feet and 21% are between 1 million – 5 million square feet (Figure 29). There is a logical relationship between these three questions where most educational facilities operate in a campus with multiple buildings with a size over 5 million square feet.

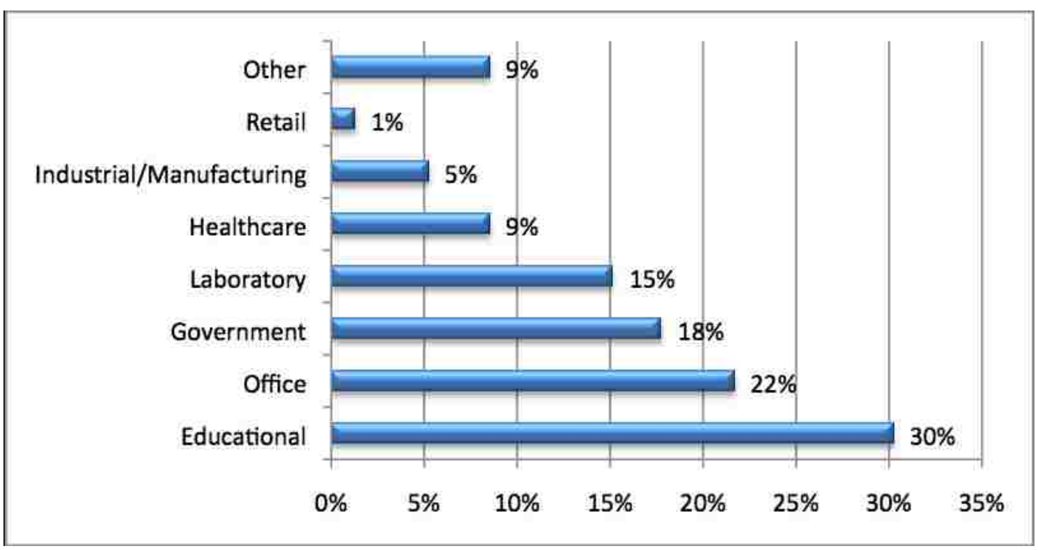

Figure 28: Primary use of facilities

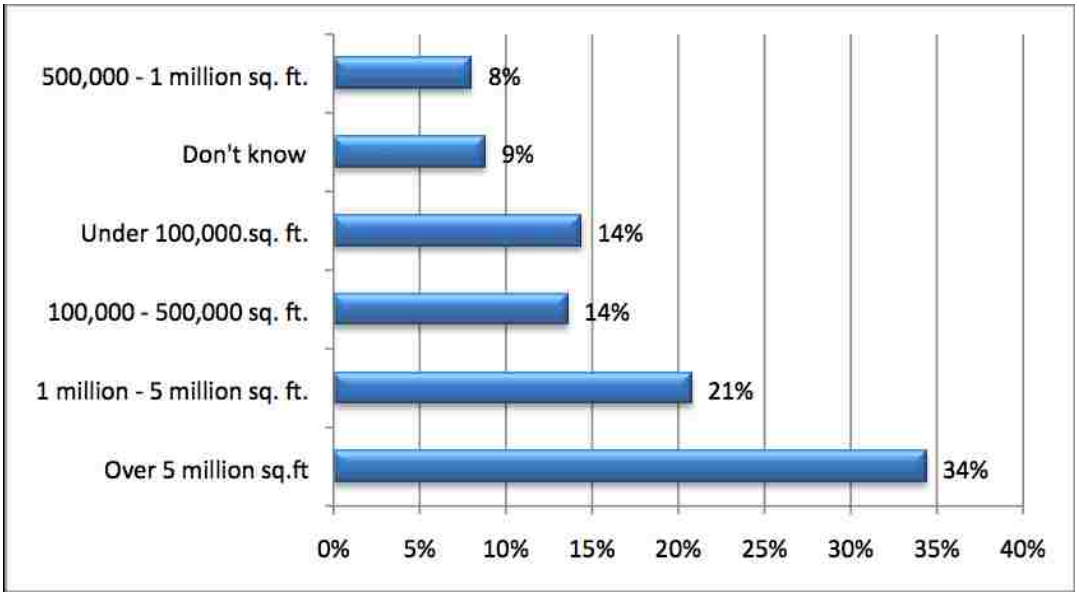

Figure 29: Size of facilities

4.3 Operations and Maintenance

Many of the questions asked in this section are strictly related to operating and maintaining facilities. All of the respondents are familiar with facilities operations, however some of them were not able to provide specific O&M information.

As described in Chapter 2, most institutions use a Computerized Maintenance Management System (CMMS) to track and generate work orders by equipment or component. One of the questions asked which CMMS system does their facility use. Respondents were able to select more than one option from the list of CMMS systems provided. Maximo by IBM is the CMMS system used by most respondents with 31%, followed by TMA with 10% and FAMIS with 5%. Twenty-six of the respondents do not know the CMMS system their facilities use. Twenty five percent selected “other” systems such as AssetWorks-AIM, FM Systems, Facility Link, Facility Focus, Archibus and company developed (Figure 30).

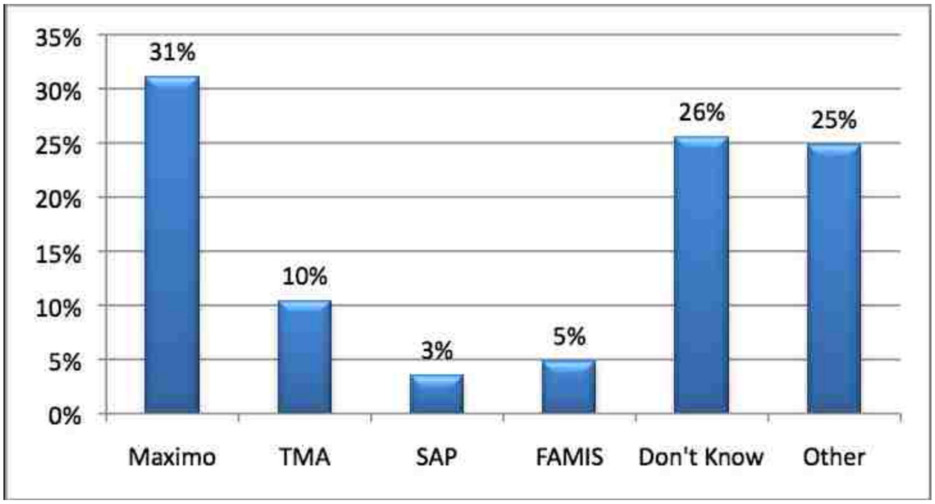

Figure 30: CMMS system used by respondents

When asked what best describes the work order preparation workflow process. Thirty four percent of the participants responded that the work plan is prepared by O&M planners and craftsmen or tradesmen perform the work. Seventeen percent of the work plan is prepared by O&M schedulers and work is performed by craftsmen or tradesmen. While only 10% percent of the work plan is prepared and performed by craftsmen or tradesmen. In the “other” category, many respondents described that in some cases it depends on the type of maintenance if is either scheduled or unscheduled. Others described that work plan workflow preparation is done by O&M planners and tradesman/craftsman, and others indicated that work is outsourced or the responsibility of the landlord. Figure 31 illustrates the respondents’ description of the work order preparation workflow process. When the percentage breakdown of scheduled and unscheduled work orders, on average respondents perform 53% on scheduled work orders and 47% on unscheduled work orders.

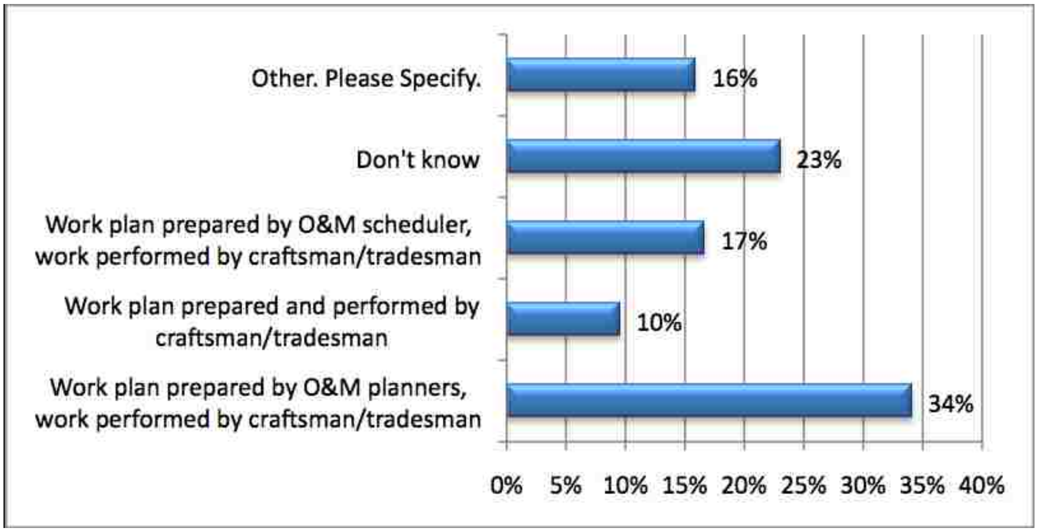

Figure 31: Respondents description of work order preparation workflow process

Another question asked to choose the number of work orders per year for their facility. Surprisingly, 40% of respondents indicated that they “don’t know” how many work orders they do in a year. Twenty-three percent indicated that they do between 0-10,000 work orders per year, 14% responded that they do 14% work orders per year, 10% indicated that they do between 10,000-30,000 work orders per year, 9% do between 40,000 and 50,000 and 4% do between 30,000 and 40,000 work orders per year (Figure 32).

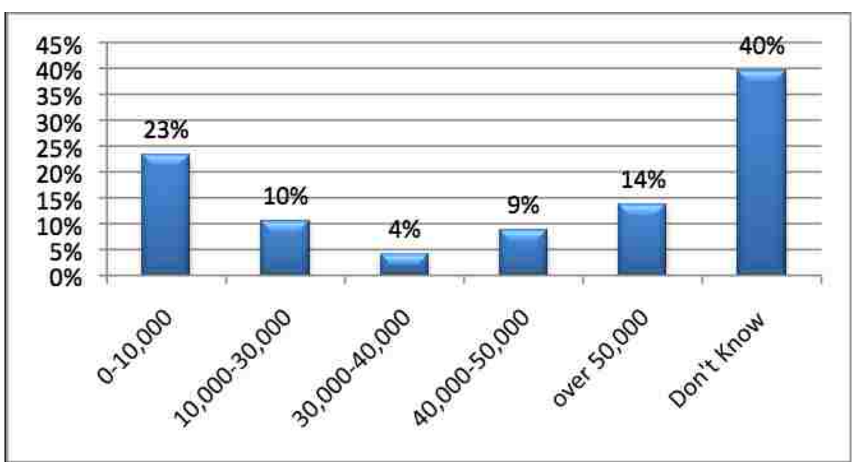

Figure 32: Number of work orders per year

The next question regarding information about O&M asked after a work order is received what is the average time spent on work order preparation. Similarly from the responses of the question asked before, 35% of the respondents “don’t know” the average time that is spent on work order preparation. Twenty-three percent of the respondents indicated that it takes under 30 minutes and 21% takes between 30 minutes to 1 hour. Thirteen percent takes between 1 – 2 hours, while 8% takes over 2 hours (Figure 33).

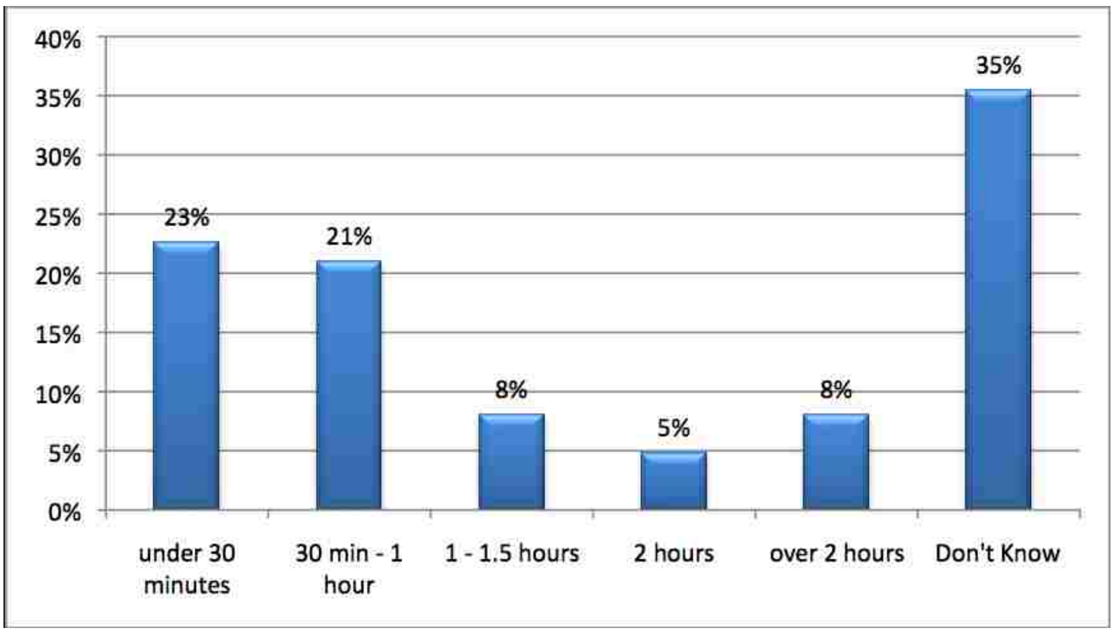

Figure 33: Average time in work order preparation

A primary objective of this research was to assess the current access to O&M information and rate the accuracy of information of as-built drawings. Accessibility to O&M information and accuracy of information of as-built drawings are critical to perform O&M efficiently. When respondents were asked to describe their current access to O&M information, 44% of the respondents described as average the current access to O&M, where most information is available but not in one place; 24% indicated that the current access to information is below average where they can find the information but it takes time; 22% responded that their access to information is above average where most information is easy accessible but not in one place, 7% described as poor their current access to O&M information where respondents never can find the information they need and 3% described it as perfect where all information is accessible in one location (Figure 34). In addition, the survey asked how would you rate the accuracy of as-built drawings. Thirty eight percent of the respondents rated the accuracy of as-built drawings as average where they occasionally use and trust the information shown. While 30% rated it below average where they will use information but do not fully trust it. Twenty three percent rated as above average, while 10% rated as poor and they rarely use and do not find information. None of the respondents rated the accuracy of information of as built drawings as perfect.

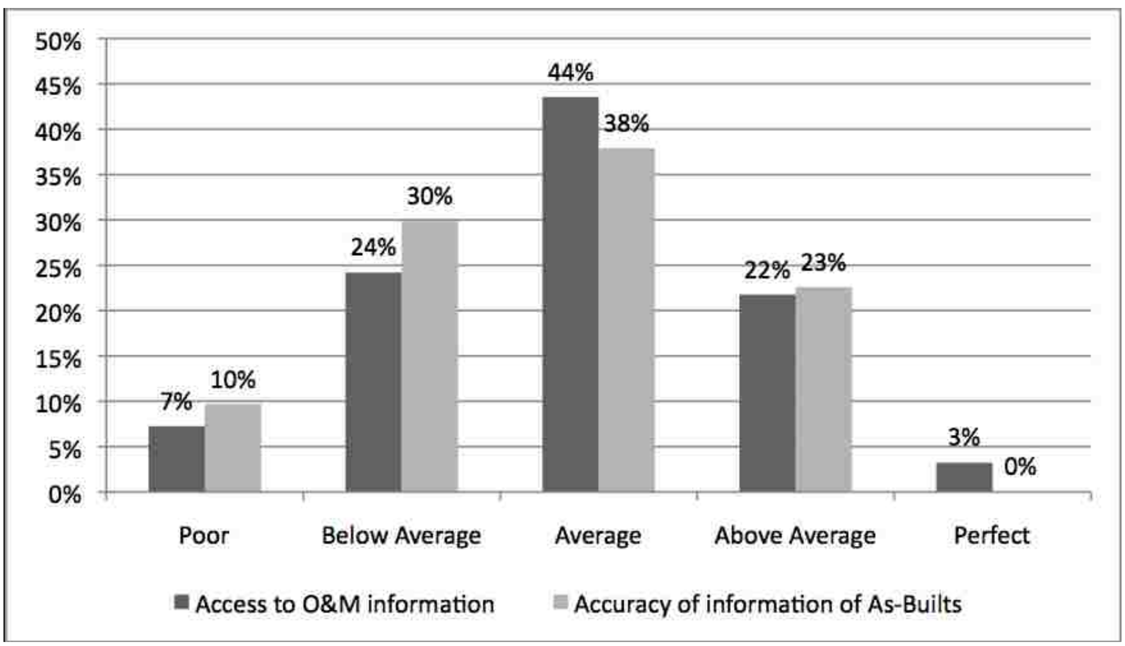

Figure 34: Respondents rating of accessibility to O&M information and accuracy of information of as-built drawings

4.4 Building Information Modeling

The main objective of this study is to assess the perceived value of using BIM in facilities O&M. An important part of this study is to assess the understanding of BIM concepts of facilities operations personnel. One of the questions in the survey asked what is the understanding behind BIM concepts. Thirty eight percent of the respondents indicated that they are familiar with the concept and surprisingly, 36% are very involved with BIM. Sixteen percent of the total are unfamiliar and 10% vaguely understand the concepts of BIM. This question however depends on the respondents perception of what they think is their understanding behind BIM concepts (Figure 35).

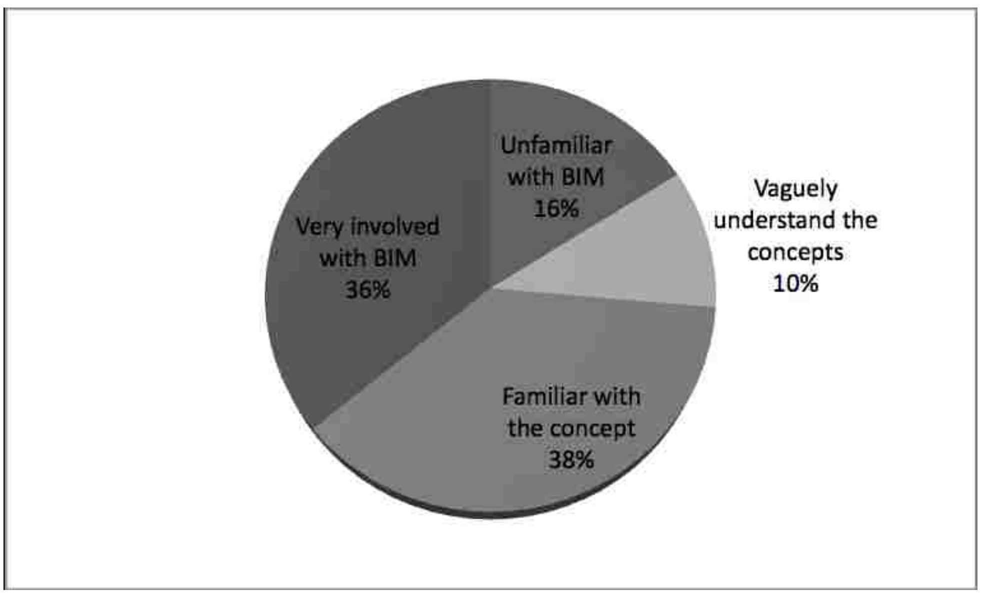

Figure 35: Respondents understanding of BIM concepts

Building Information Modeling is being widely implemented in the design and construction phase of all kinds of projects. Even though 72% are either familiar or very involved with BIM, the following questions asked if respondents use BIM in the design and construction phases. The largest percentage, 35% of the respondents do not use BIM in any phase of their projects. Conversely, 30% percent use it in design and construction.

While 18% only used it on design and 5% only use it in construction. Thirteen percent are not sure if they use BIM in any phase of their projects (Figure 36).

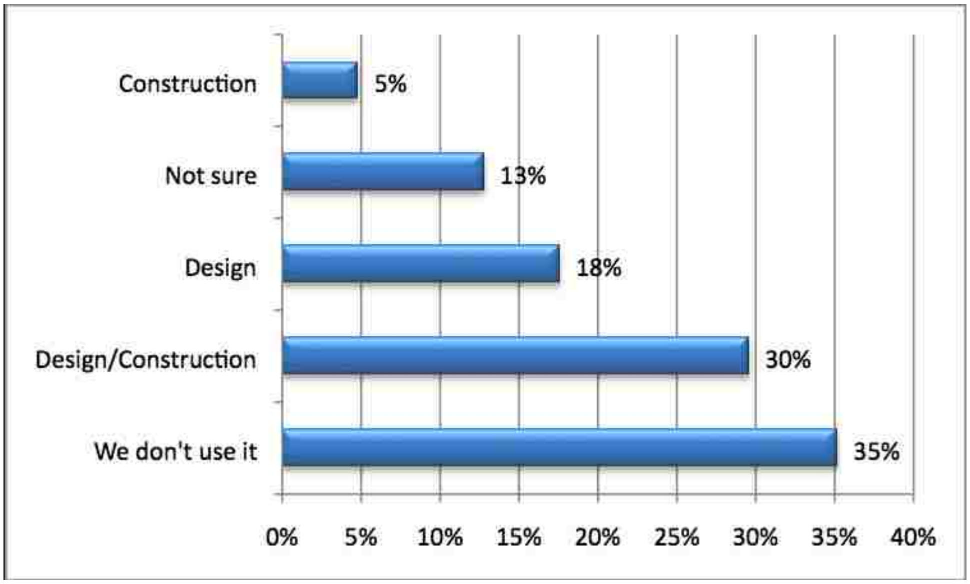

Figure 36: BIM use by respondents in their projects phases

A follow up question asked respondents to predict in how many years they see their facility using BIM for O&M. Twenty five percent responded that in 3-5 five years, while 22% percent think that they will use in 1-2 years. Surprisingly, 10% of the respondents indicated that they already using BIM for O&M. The largest percentage of respondents, 30% of the total do not know when they would use it, 7% answer that they do not think they will ever use and 6% predicted that they see their facility using BIM for O&M in 6-10 years (Figure 37).

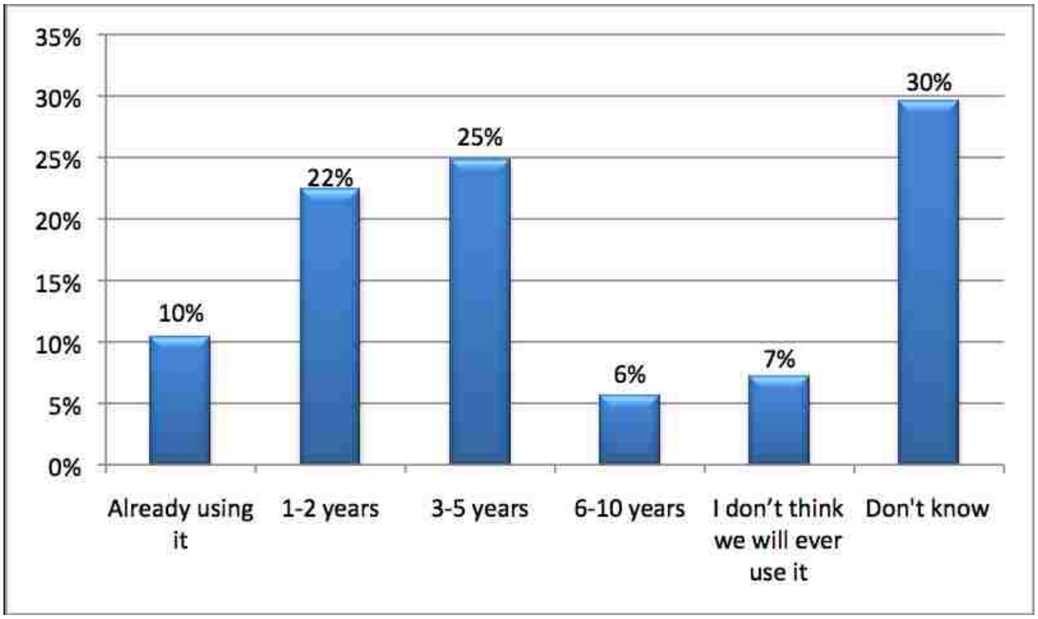

Figure 37: Respondents prediction of the use of BIM

The last open-ended question about BIM asked respondents to indicate what may be preventing their facility from using BIM. Based on coding techniques to analyze open-ended questions, forty-three respondents out of 125 provided their opinion to this question. Twenty-three percent indicated that unwillingness to change the current process is the major barrier to use BIM for O&M. The second largest percentage is costs and lack of funding to invest in BIM. The other barriers that range from 9% to 12% of the total of responses indicated that lack of understanding, personnel and resources; in addition to data update/maintenance along with lack of seamless interfaces with current software are major barriers (Figure 38).

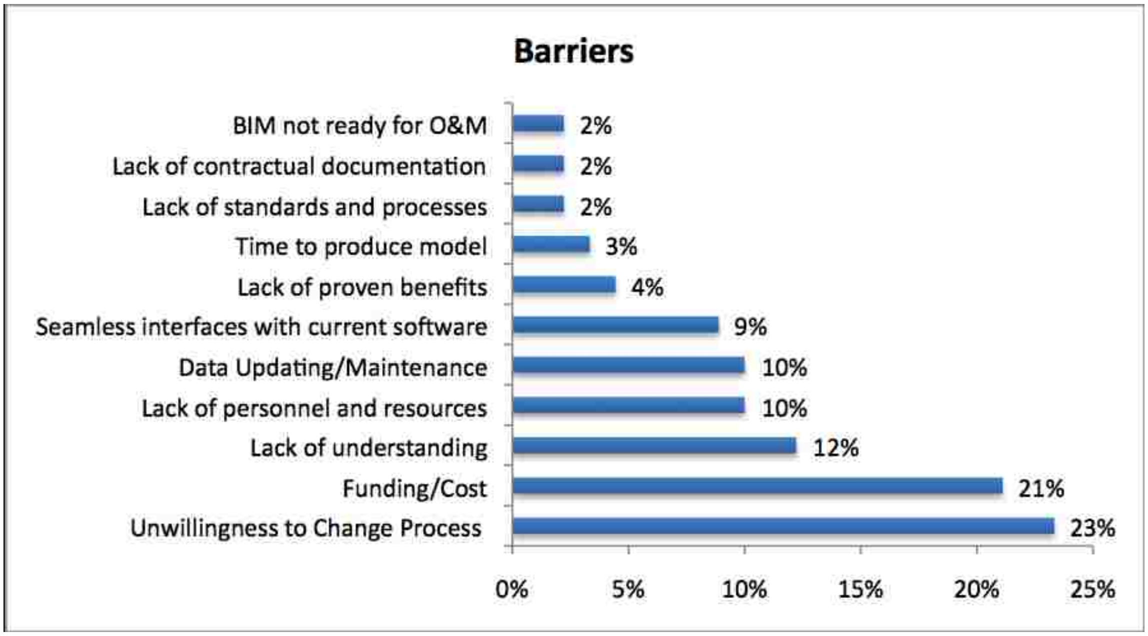

Figure 38: Barriers of that prevent the use of BIM for O&M

4.5 Perceived Use and Time Savings in Using BIM for O&M

This section of the survey assesses the main objectives of this research. After the video demonstration titled “View of the Future for FM” that demonstrates how can you access O&M information as shown in the video, the first question asked how often would you use BIM. Forty seven percent of the respondents answered that they would use it often for most of their work. While 26% said they would use it all the time and the same number of respondents would use it occasionally, while only 1% of respondents answered that would use it rarely (Figure 39).

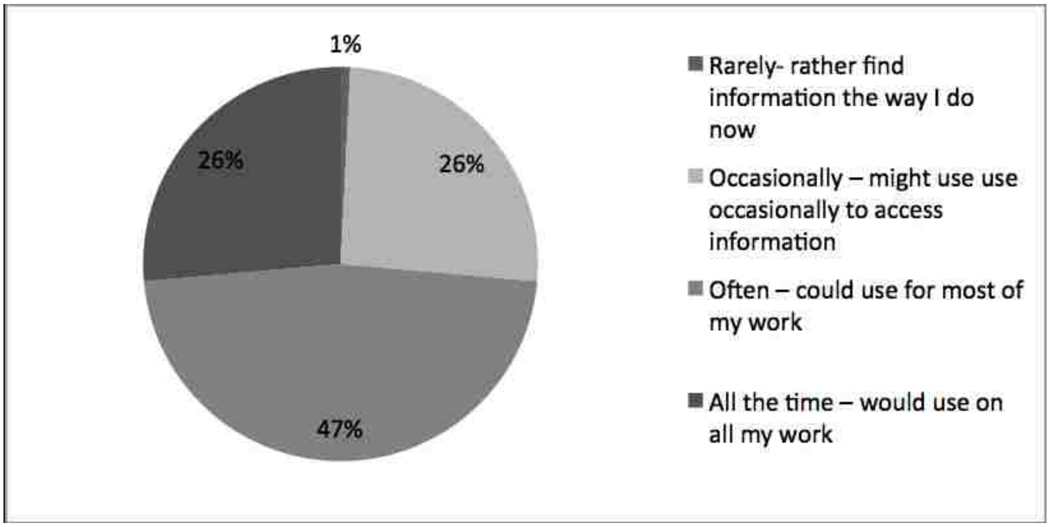

Figure 39: Perceived use of BIM

The next questions necessary to assess the perceived value of BIM, asked what percentage of their time could be saved in your work order process by using BIM as shown in the video. The vast majority, forty three percent of the respondents could not answer the question responding that they don't know. The next majority 19% answered it would save between 21-40% of their time in their work order process, 18% answered that it would save between 11-20% of their time, while only 1 person said that it would not save any time (Figure 40).

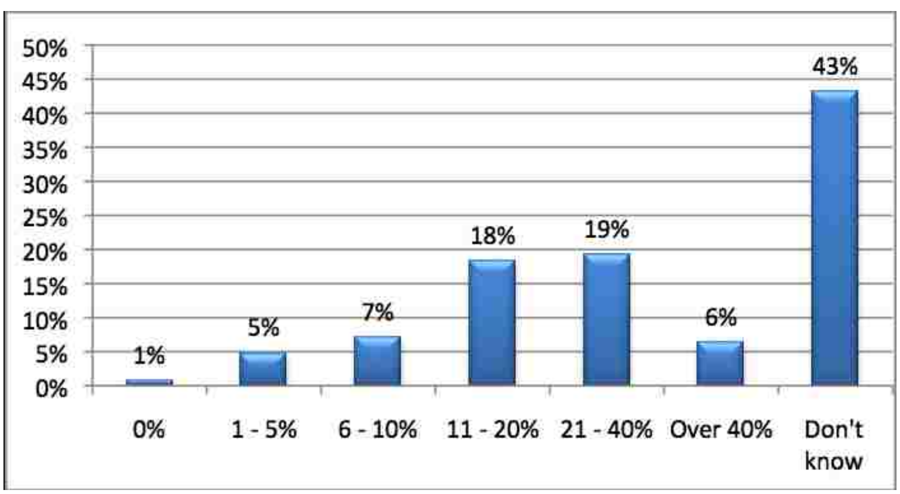

Figure 40: Perceived time savings in work order process with BIM

Unscheduled work orders usually cost more money as shown in Chapter 2, thus the need to have access to information efficiently is critical to respond rapidly to unexpected emergencies. The questions asked what effect would BIM have on their response time to unscheduled work orders if we could use BIM as shown in the video. The highest percentage, 52% responded that it would decrease their response time, 27% percent do not know, 18% percent answered that it would not have any change and 3% said that it will increase the response time (Figure 41).

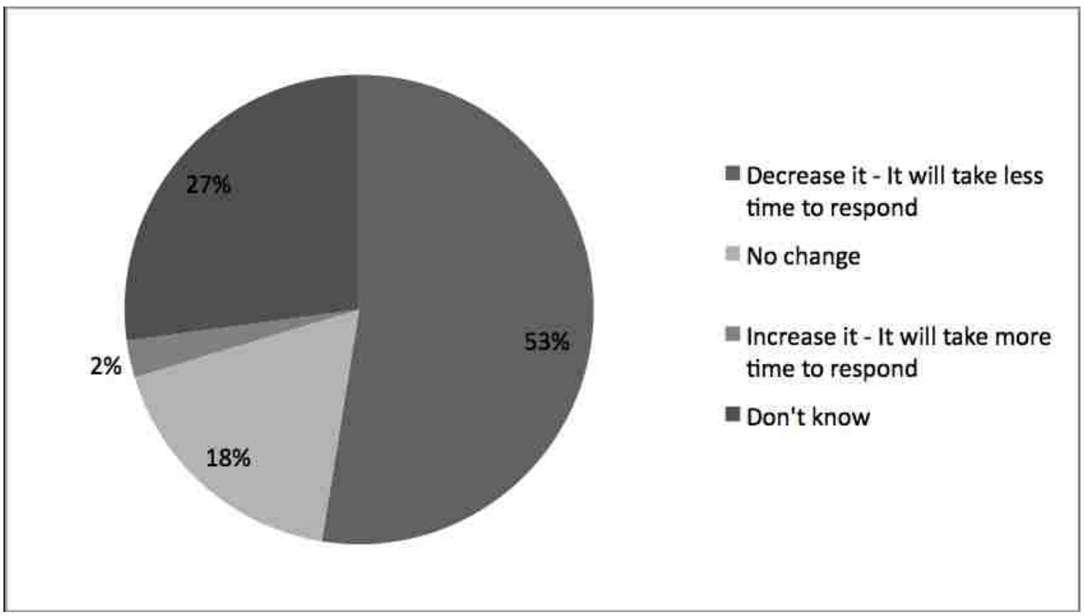

Figure 41: Effect on response time using BIM

The last question on the survey asked respondents to rank the best benefits of using BIM for O&M as shown in the video. Respondents were provided with a table with four selected best benefits and their ranking from 1 – 4 scale on what they perceived was the best benefit, 1 representing the best benefit. Better access to O&M information was ranked as the best benefit by most respondents, followed by centralized location for information, integration with Asset Management System and ultimately, 3D visualization.

Table 3: Rank of best benefit of BIM in O&M

Benefit	Rank			
	1	2	3	4
Better access to O&M information	40%	27%	20%	13%
Centralized location for information	29%	30%	31%	10%
Integration with Asset Management System	26%	23%	25%	26%
3D Visualization	14%	22%	18%	46%

CHAPTER 5 DATA ANALYSIS

5.1 Overview

This chapter presents the data analysis of the responses obtained from the online survey. This aims to analyze the respondents' answers to the research questions and relationships that exist in the responses. The Pearson Chi-Square test of independence was used as the most appropriate technique to test the relationship between two discrete variables. In addition, the data analysis also used descriptive analysis to calculate the median and mean to obtain more results from the survey.

5.3 Perceived Future Use of BIM for O&M

A total of 125 responses were collected from the survey. The first question of this research was to determine how often would facilities operations personnel use BIM to access O&M information. Almost half of the respondents, 47% of the total indicated that they would "often" use BIM to access O&M information. Twenty six percent answered that they would use BIM "all the time" and the same number of people indicated that they would use it "occasionally". While only 1 person answered that it would use BIM rarely. Combining the answers from the respondents that would use BIM "often" and "all the time", 73% of facilities operations personnel would use BIM to access O&M information. Based on these responses we can conclude that more than 70% of the respondents would use BIM regularly to access O&M information.

One of the questions on the survey asked what is the understanding about the concept behind BIM. Thirty eight percent of the respondents answer they are familiar with the concept and 36% indicated that are very involved with BIM. Combining these two groups, 74% of respondents are knowledgeable about BIM concepts. This high percentage could be related to how often respondents perceived they would use BIM to access O&M information. To determine this relationship a Pearson Chi-square test of independence was performed to determine if their knowledge about BIM is related to how often they would use BIM to access O&M information.

Null Hypothesis: No relationship exists between the respondent's knowledge of BIM and how often they would use BIM to access O&M information.

Alternative Hypothesis: A relationship exists between the respondent's knowledge of BIM and how often they would use BIM to access O&M information..

Level of significance: $\alpha = 0.05$

Table 4: Cross-tabular analysis of Future Use of BIM to access O&M information and Understanding of BIM Concepts

Understanding of BIM	Future Use of BIM to access O&M information		
	Rarely/Occasionally	Often/All the time	Row Totals
Unfamiliar/Vaguely Familiar	12	21	33
Familiar/Very Involved	21	71	92
Column Totals	33	92	125

The chi square test was performed using SPSS and delivered the following results:

Table 5: Understanding of BIM * Future Use to Access O&M Information Cross tabulation

			Future Use		Total
			Often/ All time	Rarely/ Occasionally	
Understanding of BIM	Familiar/ Very involved	Count	71	21	92
		Expected Count	67.7	24.3	92.0
		% within Understanding	77.2%	22.8%	100.0%
		% within Use	77.2%	63.6%	73.6%
		% of Total	56.8%	16.8%	73.6%
		Std. Residual	.4	-.7	
	Unfamiliar/ Vaguely familiar	Count	21	12	33
		Expected Count	24.3	8.7	33.0
		% within Understanding	63.6%	36.4%	100.0%
		% within Use	22.8%	36.4%	26.4%
		% of Total	16.8%	9.6%	26.4%
		Std. Residual	-.7	1.1	
Total		Count	92	33	125
		Expected Count	92.0	33.0	125.0
		% within Understanding	73.6%	26.4%	100.0%
		% within Use	100.0%	100.0%	100.0%
		% of Total	73.6%	26.4%	100.0%

The cross-tabulation table produced by SPSS (Table 5) contains the number of cases that fall in into each combination of categories and is similar to the table 4. From the table we can conclude that in total 92 respondents (73. 6% of total) would use BIM either often or all the time to access O&M information, and of these 71 (77.2% of the total that would use often/all time) are familiar or very involved with BIM and 21 (22.8%) are unfamiliar or vaguely familiar. Further, 33 (26.4% of total) indicated that they would use either rarely or occasionally, 21 (63.6% of the total that would use rarely/occasionally) are familiar/very involved with BIM, while 12 (36.4% of the total that would use rarely/occasionally) are unfamiliar or vaguely familiar with BIM. The table also describes that 72.2% percent of the people who are familiar/very involved with BIM would use BIM either often or all the time to access O&M information, while 22.8% would use it rarely or occasionally. Similarly, those respondents that are unfamiliar or vaguely familiar 63.6% would use BIM either often or all the time, while 36.4% would rarely or occasionally to access O&M information. In summary, most respondents would use BIM to access O&M information without depending of their current understanding of BIM concepts.

The chi-squared value for this cross-tabular comparison shown in table 7 is 2.29. This gives a ρ value 0.13> 0.05. We accept the null hypothesis; the respondents' familiarity with BIM concepts does not depend on how often they would use BIM for O&M. Even tough the Chi Square analysis determined that there is no relationship; the ρ value is not significantly higher than the level of significance. The reason that the test determined that there is not relationship might be that respondents that very unfamiliar or vaguely familiar with BIM could visualize through the video how they could use BIM in O&M work.

Table 6: Chi-Square Test Understanding of BIM * Future Use to Access O&M Information

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.291[a]	1	.130		
Continuity Correction[b]	1.647	1	.199		
Likelihood Ratio	2.199	1	.138		
Fisher's Exact Test				.167	.101
N of Valid Cases	125				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.71.

Further analysis using the Chi-square test of independence was performed to determine the relationship between sets of categorical data. The following analysis studied if the understanding of BIM concepts is related to how respondents perceived time savings of using BIM for O&M. Table 7 shows the cross tabulated table between these two variables. In this case only we considered the responses that estimated a percentage of time savings giving a total of 71 responses.

Table 7: Cross-tabular analysis of Understanding of BIM Concepts and Perceived Time Savings

Understanding of BIM		Time Savings		Total
		0-20%	**Over 20%**	
Familiar/Very Involved	Observed	28	24	52
	Expected	28.6	23.4	52
Unfamiliar/Vaguely Familiar	Observed	11	8	19
	Expected	10.4	8.6	19
Total	Count	39	32	71
	Expected	39	32	71

Null Hypothesis: No relationship exists between understanding of BIM concepts and the perceived time savings in the use of BIM for O&M.

Alternative Hypothesis: A relationship exists between understanding of BIM concepts and the perceived time savings in the use of BIM for O&M.

Level of significance: $\alpha = 0.05$

The chi-squared value shown in table 8 is 0.092. This gives a ρ value of 0.761> 0.05. This value is significantly larger than the level of significance. Thus, the null hypothesis is accepted; there is no relationship between the understanding of BIM concepts and the how they perceived the time savings in the use of BIM for O&M. Therefore, we can conclude that their understanding of BIM concepts does not depend of how respondents perceived time savings in the use of BIM for O&M. In this case the there is strong evidence that shows there is no relationship between these two variables. The reason is because there is not a significant difference in the responses from both groups.

Table 8: Chi Square Test Understanding of BIM Concepts and Perceived Time Savings

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.092[a]	1	.761		
Continuity Correction[b]	.001	1	.973		
Likelihood Ratio	.092	1	.761		
Fisher's Exact Test				.794	.488
N of Valid Cases	71				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.56.

b. Computed only for a 2x2 table

Table 9 shows the cross-tabulated table between the current use of BIM and the future use of BIM for facilities O&M. A Chi Square test was performed to determine if the current use of BIM is related to the future use of BIM for O&M.

Table 9: Cross-tabular analysis of Current Use of BIM and Future Use of BIM for O&M

Current BIM Use		Future Use		Total
		Often/All Time	Rarely/Occasionally	
Design and Construction	Observed	33	4	37
	Expected	26.4	10.6	37
Design or Construction	Observed	22	12	34
	Expected	24.2	9.8	34
Do not use it	Observed	27	17	44
	Expected	31.4	12.6	44
Total	Observed	82	33	115
	Expected	82	33	115

Null Hypothesis: No relationship exits between the current use of BIM and the future use BIM for O&M.

Alternative Hypothesis: A relationship exits between the current use of BIM and the future use BIM for O&M.

Level of significance: $\alpha = 0.05$

The chi-squared value shown in table 10 is 8.633. This gives a ρ value $0.013<0.05$. This value is smaller than the level of significance. Thus, we reject the null hypothesis; a relationship exits between the current use of BIM and the future use of BIM in O&M. Therefore, this value implies that the current use of BIM is related with the future use of BIM for O&M. For instance, most respondents (91%) that currently use BIM for design and construction answered that they would use BIM either often or all time. On the other hand respondents that do not use BIM, only 61% answered to be using either often or all the time. Based on this analysis we can imply that current users of BIM answered to be using BIM for O&M more often than non users.

Table 10: Chi Square Test Current Use of BIM and Future Use of BIM for O&M

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.633[a]	2	.013
Likelihood Ratio	9.662	2	.008
N of Valid Cases	115		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 9.76.

The size of the facilities was important variable in the survey responses. Thirty-five of the respondents work in facilities over 5 million square feet, which is the largest group in this survey. Therefore the analysis will look into relationships between the size of the facilities between and other variables. The first analysis was to determine if the size of facilities is related with the current use of BIM for design and construction. Table 11 shows the cross tabulated table between these two variables.

Table 11:Cross-tabular analysis of and Size of Facilities and Current Use of BIM

Size of facilities		Current Use			Total
		Design or Construction	Design and Construction	Don't use it	
0-5 Million Sq. Ft.	Observed	13	22	31	66
	Expected	17.6	22.9	25.5	66
Over 5 Million Sq. Ft.	Observed	14	13	8	35
	Expected	9.4	12.1	13.5	35
Total	Observed	27	35	39	101
	Expected	27	35	39	101

Null Hypothesis: No relationship exists between the size of the facilities and the current use of BIM in design/construction.

Alternative Hypothesis: A relationship exists between size of facilities and the current use of BIM in design/construction.

Level of significance: $\alpha = 0.05$

The chi-squared value for this cross-tabular comparison is 7.066 shown in table 12. This gives a ρ value of $0.029<0.05$. We reject the null hypothesis; the size of the facility is related with the current use of BIM. Therefore, we can conclude that size of the facility is related if respondents are currently using BIM. A closer look at table 11 tells us that the large groups of respondents do not use BIM in any phase of construction. However, larger facilities over 5 million square foot responded to use BIM more often than facilities below 5 million square foot. Facilities between 0 – 5 million square feet, 47% do not use BIM in any phase. On the other hand, most of larger facilities (77%) over 5 million square feet use BIM in design, construction or both.

Table 12: Chi Square Test Size of Facilities and Current Use of BIM

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.066[a]	2	.029
Likelihood Ratio	7.193	2	.027
N of Valid Cases	101		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 9.36.

The second analysis within the size of facilities was to test if the size of facilities is related to the future use of BIM for O&M. Further analysis was performed to determine if the size of facility is independent of how respondents perceived the future use. The Chi-square test was performed to determine this relationship. Table 13 shows the cross tabulated table between these two variables. In this case only we considered the responses that estimated a percentage of time savings.

Table 13:Cross-tabular analysis of and Size of Facilities and Future Use of BIM in O&M

Size of facilities		Future Use		Total
		Often/All time	Rarely/Occasionally	
0 - 5 Million Sq. Ft.	Observed	52	18	70
	Expected	51.5	18.5	70.0
Over 5 Million Sq. Ft.	Observed	40	15	55
	Expected	40.5	14.5	55.0
Total	Observed	92	33	125
	Expected	92.0	33.0	125.0

Null Hypothesis: No relationship exists between the size of a facility and future use of BIM to access O&M information.

Alternative Hypothesis: A relationship exits between the size of a facility and future use of BIM to access O&M information.

Level of significance: $\alpha = 0.05$

The chi-squared value for this cross-tabular comparison in table 14 is 0.038. This gives a ρ value 0.844>0.05. We accept the null hypothesis; the size of a facility does not depend on how often respondent would use BIM to access O&M information. Based on the responses there is no relationship between the size of the facilities and future use of BIM for O&M.

Table 14: Chi Square Test Size of Facilities and Future Use of BIM in O&M

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.038[a]	1	.844		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.038	1	.845		
Fisher's Exact Test				.841	.502
N of Valid Cases	125				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 14.52.

b. Computed only for a 2x2 table

The third analysis concerned with the size of the facilities determined if the size of facility is related to the perceived time savings. The Chi-square test was performed to determine this relationship. Table 15 shows the cross tabulated table between these two variables. In this case only we considered the responses that estimated a percentage of time savings.

Table 15:Cross-tabular analysis of and Size of Facilities and Perceived Time Savings

Size of Facilities		Time Savings		Total
		0-20%	Over 20%	
0-5 Million Sq. Ft.	Observed	27	16	43
	Expected	23.6	19.4	43
Over 5 Million Sq. Ft.	Observed	12	16	28
	Expected	15.4	12.6	28
Total	Observed	39	32	71
	Expected	39	32	71

Null Hypothesis: No relationship exists between the size of a facility and perceived time savings.

Alternative Hypothesis: A relationship exits between the size of a facility and perceived time savings.

Level of significance: $\alpha = 0.05$

The chi-squared value for this cross-tabular comparison shown in table 16 is 2.722. This gives a ρ value 0.09>0.05. We accept the null hypothesis; the size of a facility is not related to the perceived time savings. However, the ρ value is not significantly higher than the level of significance. The majority of the respondents within facilities below 5 million square feet see benefits between 0-20% while the majority of respondents within facilities over 5 million square feet see benefits over 20%.

Table 16: Size of Facilities and Perceived Time Savings

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.722[a]	1	.099		
Continuity Correction[b]	1.976	1	.160		
Likelihood Ratio	2.728	1	.099		
Fisher's Exact Test				.143	.080
N of Valid Cases	71				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 12.62.

b. Computed only for a 2x2 table

Table 17 summarized the results obtained from the Chi Square tests performed to determine the relationship between different variables. It is important to notice that for the first analysis understanding of BIM concepts vs. Future Use of BIM for O&M the test indicates there is no relationship. However, the ρ value is not significantly larger than the significance value of 5%. Thus, with a larger set of data there could in fact be a relationship between these two variables.

Table 17: Summary of Chi Square Tests

Analysis	[redacted]	ρ	Result
Understanding of BIM Concepts vs. Future Use of BIM for O&M*	2.291	0.13	No Relationship
Understanding of BIM Concepts vs. Perceived Time Savings	0.092	0.761	No Relationship
Current Use of BIM vs. Future Use of BIM in O&M	8.633	0.013	Relationship
Size of Facilities vs. Current Use of BIM	7.066	0.029	Relationship
Size of Facilities vs. Future Use of BIM in O&M	0.038	0.844	No Relationship
Size of Facilities vs. Perceived Time Savings*	2.722	0.099	No Relationship

5.4 Perceived Time Savings in the Work Order Process Work Flow

The second objective of this study was to determine the percentage of time that BIM would save in the work order process workflow. In this analysis, 71 people provided an estimate of how much time BIM could save in their work order process workflow. Thirty four percent of the respondents who provided an estimate for time savings estimated that BIM could save between 21 to 40 percent of their time, 32% estimated that it could save between 11 to 40 percent in their work order process workflow. While, 13% percent estimated time saving between 6 and 10 percent, 11% indicated savings over 40%, 8% between 1 and 5 percent and 1% stated no time savings. Based on the bar chart (Figure 41), the median indicated an approximate of 25.5 % of time savings in work order process work flow by the use of BIM.

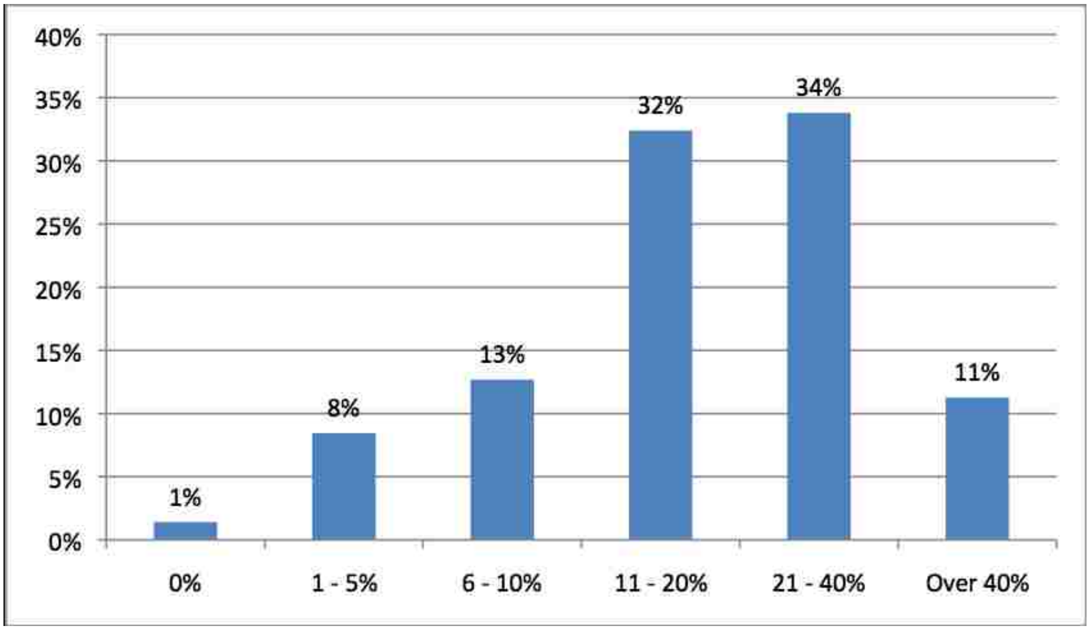

Figure 42: Percentage of time saving in work order process workflow

5.5 Effect on Response Time to Unscheduled Work Orders

The third objective of this survey was to determine what effect BIM would have in the response time to unscheduled work orders. As stated in Chapter 2, unscheduled work orders have the need to access O&M information and as built drawing in emergency situations. In addition, unscheduled work orders usually have a higher cost than scheduled work orders. Based on the answers by respondents on average 53% of the work orders are scheduled and 47% are unscheduled. More than half of the respondents (53%) indicated that the use of BIM as shown in the video would decrease the response time to unscheduled work orders (Figure 42). Therefore, the use of BIM for O&M can be useful to decrease the response time on unscheduled work orders.

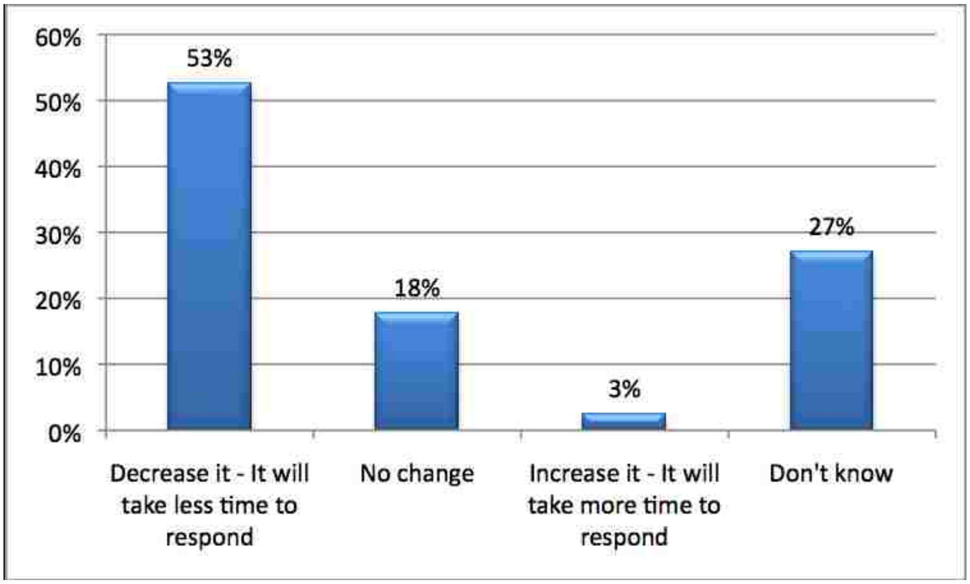

Figure 43: Perceived effect on unscheduled work orders

5.6 Benefits of using BIM for O&M

Based on the literature review and interviews with O&M experts a list of four benefits was provided to respondents. They were asked to rank on a scale from 1 to 4, which was the best benefit of using BIM for O&M, 1 being the best benefit and 4 being the last important benefit. Table 8 ranks the four benefits in order of best benefit reporting the number of cases and standard deviation.

Table 18: Ranking of best benefits of O&M

Benefit	Mean	Std. Deviation
Better access to O&M information	2.08	1.029
Centralized location for information	2.408	1.071
Integration with Asset Management System	2.568	1.131
3D Visualization	2.992	1.074

As shown in Chapter 4, respondents rated better access to O&M information as the best benefit. On a scale from 1 to 4, where 1 was the most benefit and 4 the least benefit, 40% of the respondents attributed the score of 1 to better access to O&M information. With a mean of 2.08, then centralized location of information is ranked as the second best benefit (2.408), followed by integration with Asset Management System (2.568) and ultimately 3D Visualization (2.992). It is interesting to note that from respondents that are already using BIM for O&M better access to O&M remains as the best benefit while integrations with Asset Management System is the second best benefit, followed by “centralized location of information” and “3D visualization”.

Table 19:Ranking of best benefits by BIM user in O&M

Benefit	Mean	Std. Deviation
Better access to O&M information	2.12	1.01
Integration with Asset Management System	2.38	0.97
Centralized location for information	2.46	1.14
3D Visualization	3.08	1.19

CHAPTER 6 CONCLUSIONS

Operating and maintaining facilities efficiently is critical for extending the lifecycle of a building. The costs of inefficient conventional processes in accessing relevant O&M information are extremely high and mostly absorbed by owners after the construction phase. Building Information Modeling (BIM) is one of the most promising technological developments in the construction industry with the capability to overcome these inefficiencies. Proven benefits in the design and construction phase are motivating owners to use BIM in the O&M phase. However, unwillingness to process change, lack of knowledge, lack of defined processes of information exchange, and lack of documented metrics is preventing BIM implementation in the O&M phase. The purpose of this research is to overcome some of these issues and to determine the perceived value and future benefits of using BIM in the facilities O&M phase.

6.1 Conclusions

Based on the responses of 125 facilities operations personnel, this research has determined that more than two thirds of the respondents would use BIM either often or all the time to access O&M information. Almost half of the respondents would use it often, while a quarter of the respondents would use it all the time. Twenty six percent would use it occasionally and only 1 person indicated that it would rarely use BIM to access O&M information, concluding that most respondents perceived the use of BIM as a great tool for the O&M phase.

The research further establishes that the future use of BIM for O&M is related to the current of use of BIM. For instance, owners that are currently using BIM in the design and construction phases answered that they would use BIM for O&M more frequently than owners that are not using BIM in any phase of their projects. This relationship could be because owners that are currently being exposed and experienced the benefits of BIM in design and construction see opportunities to extend those benefits to the O&M phase. In addition, the current use of BIM in design and construction is related to the size of the facilities. Larger facilities over 5 million square feet are currently using BIM more often than facilities below 5 million square feet. BIM has demonstrated to have great benefits on large complex projects therefore its use seems to be more common in large projects.

On the other hand, this study determined that the understanding of BIM concepts has no relationship with how they perceived the time savings in processing work orders. Most respondents that are familiar or unfamiliar with BIM concepts range the time savings from 0-20%. Also, the size of the facilities is not related with how they would use BIM for O&M in the future. Thus, the use of BIM for O&M is perceived to have a frequent use by large and small facilities. Although the Chi Square test determined that the understanding of BIM concepts has no relationship with future use of BIM for O&M, the evidence from the chi square test is not strong enough. Respondents that are more familiar with BIM concepts answered to be using BIM for O&M more frequent than respondents that are not familiar. Similarly, when the relationship of size of the facilities and the perceived time savings was tested, larger facilities perceived greater time savings than smaller facilities. Larger facilities manage a larger number of buildings in single campus; thus having the information in a single location can be perceived to have greater percentage of time savings in processing work orders.

In determining how much percentage of time would be saved in the work order process workflow, most respondents (43%) were not able to give an answer. For the respondents who provided an estimate of time savings, most of the respondents 66%, estimated savings between 11 – 40 percent. This study concluded that most respondents perceived that they could save 25 % of their in their work orders process workflow by using BIM.

Unscheduled work orders are critical and the need to access accurate information is important to respond rapidly in these situations. More than half of the respondents (53%) indicated that the use of BIM for O&M would decrease their response time to unscheduled work orders.

Most respondents agreed that better access to O&M information is the best benefit, followed by centralized location of information, integration with asset management system and ultimately 3D visualization. Respondents that are already using BIM for O&M ranked better access to O&M information as their best benefit followed by integration with asset management system as their second best benefit.

6.2 Implication by practitioners

Based on the results obtained from this research it can be concluded that BIM can be a useful tool for the O&M phase. Its capability to organize structured information has the potential to overcome the inefficiencies encountered in the O&M phase. Owners should start investigating the possibility to obtain a model as a deliverable to be used in the O&M phase. This research also demonstrated that owners with more knowledge and exposure to BIM projects see greater benefits than owners that are not currently using BIM. Owners that are unfamiliar with about BIM concepts were able to see through a video and respond to the future benefits that it can provide in their work.

6.3 Implications by researchers

Future research should focus in creating process to exchange information consistently during project phases and use that information for the building lifecycle. In addition, future studies can focus to determine what information is necessary to gather from designers and contractors and be included in the model to be delivered owners at the completion of a project. It should also study owners that are currently using BIM for O&M in their projects and report the benefits and barriers that are encountering in the implementation.

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APPENDIX 1

Survey Questions

BIMWORKX THE UNIVERSITY of NEW MEXICO

Section A: GENERAL INFORMATION

A.1) Your name:

A.2) Company/Organization name:

A.3) E-mail:

A.4) What is your primary job responsibility?

☐ Operation &Maintenance Planner

☐ Craftsman/Tradesman

☐ Technician

☐ Facilities Engineer

☐ Facilities Manager

☐ Other. Please specify____________________

A.5. How many other people share your same job responsibility in your organization?

Number of people_________________________

Section B: FACILITY DESCRIPTION

B.1) Which best describes your facility:

☐ One building in a single location

☐ Individual buildings in multiple locations

☐ Campus with multiple buildings

☐ Other. Please specify____________________

B.2) What is the primary use of your facility:

☐ Office

☐ Retail

☐ Industrial/Manufacturing

☐ Government

☐ Healthcare

☐ Educational

☐ Laboratory

☐ Hospitality

☐ Other________________________

B.3) What is the size of the facilities you manage?

☐ Under 100,000.sq. ft.

☐ 100,000 - 500,000 sq. ft.

☐ 500,000 - 1 million sq. ft.

☐ 1 million - 5 million sq. ft.

☐ Over 5 million sq.ft

☐ Don't Know

Section C: OPERATION & MAINTENANCE (O&M)

C.1) Total number of Work Orders per year for your facility

- ☐ 0-10,000
- ☐ 10,000-30,000
- ☐ 30,000-40,000
- ☐ 40,000 – 50,000
- ☐ over 50,000
- ☐ Don't know

C.2) What is the average time spent on Work order preparation?

- ☐ under 30 minutes
- ☐ 30 min -1 hour
- ☐ 1- 1.5 hours
- ☐ 2 hours
- ☐ over 2 hours
- ☐ don't know

C.3) What best describes your Work Order preparation work flow process?

- ☐ Work plan prepared by O&M planners, work performed by craft
- ☐ Work plan prepared and performed by craft
- ☐ Work plan prepared by O&M scheduler, work performed by craft
- ☐ Don't know
- ☐ Other. Please Specify ______________________________

C.2) What best describes your current accessibility to O&M information?

- ☐ Poor – Never can find what I needed
- ☐ Below Average – Find some information, but takes time
- ☐ Average – Most information is available, but not in one place
- ☐ Above Average – Most information is easily accessible, but not in one place
- ☐ Perfect- All information is ready available in one location

C.3) How would you rate the accuracy of information on As-Built drawings?

☐ Poor – Rarely use, do not trust information

☐ Below Average – Use but do not trust information

☐ Average – Most information is correct, but incomplete

☐ Above Average – Often use and trust information shown, but incomplete

☐ Perfect- All information is provided and can trusted

C.4) Which Asset Management applications does your facility use?

☐ Maximo

☐ TMA

☐ SAP

☐ Don't Know

☐ Other. Please Specify___________________

C.5) How many work orders do you do in a day, week or month? Only provide one entry below

Day_______

Week______

Month______

C.6) What is the percentage breakdown for scheduled and unscheduled work orders?

Please fill in the blank with an estimate percentage for each.

Scheduled_________

Unscheduled______

Section D: BUILDING INFORMATION MODELING

D.1) What is your understanding about the concept behind building information modeling?

☐ Unfamiliar with BIM

☐ Vaguely understand the concepts

☐ Familiar with the concept

☐ Very involve with BIM

D.2) Do you currently use BIM in any phases of your construction projects?

☐ Design ☐ Construction ☐ We don't use it ☐ Not sure

D.3) In how many years do you see your facility using BIM for O&M?

☐ Already using it

☐ 1-2 years

☐ 3-5 years

☐ 6 – 10 years

☐ I don't think we will ever use it

☐ Don't know

D.4) What may be preventing your facility from using BIM?

____

____

(After video)

Section E: VIEW OF THE FUTURE FOR FM

E.1) If you could now access O&M information using Building Information Model (BIM) as shown in the video, how often would you use it?

- ☐ Rarely- rather find information the way I do now
- ☐ Occasionally – might use occasionally to access information
- ☐ Often – could use for most of my work
- ☐ All the time – would use on all my work

E.2) If you could access O&M information using BIM, what percentage (%) of time could you save on your Work Order Process?

- ☐ 0%
- ☐ 1-5%
- ☐ 6-10%
- ☐ 11-20%
- ☐ 21-40%
- ☐ Over 40%
- ☐ Don't know

E.3) If you could access O&M information using BIM as shown in the video, what effect would it have on your response time to unscheduled work orders?

- ☐ Decrease it - It will take less time to respond
- ☐ No change
- ☐ Increase it - It will take more time to respond
- ☐ Don't know

E.4) Which describes the best benefit of using BIM for O&M? Based on the video "View of the Future for FM". Rank in order of best benefit, 1 being most beneficial, 4 being least beneficial.

Benefit	1	2	3	4
Better access to O&M				
3D visualization				
Centralized location of information				
Integration with Asset Management System				