12-2014

Building Information Modeling: Beyond Design, Commissioning and Construction

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BUILDING INFORMATION MODELING: BEYOND DESIGN, COMMISSIONING AND CONSTRUCTION

A Thesis
Presented to
The Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Construction Science and Management

by:
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December 2014

Accepted by:
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ABSTRACT

Building Information Modeling (BIM) is continuing to grow in popularity among contractors and more recently among owners as the complexity and usefulness of models are improved. Many construction firms have used BIM or adopted it in their practices to some degree. However, while it is growing in popularity, its use in facility management by the owner is still lagging. This research examines how construction processes can be better organized to supply the owner a BIM that would be useful for facility management activities.

The research was conducted to identify successful post-construction BIM implementation practices and the ways in which contractors supported these processes. The research found trends among BIM execution practices of advanced contractors and owners. A common obstacle to contractors' ability to provide owners with useful models was uncovered, leading to the creation of a proposed process for creating a model that meets the needs of facility management activities.

The research utilized case studies to identify the BIM creation processes used by advanced BIM users. In-depth interviews focused on the processes used by the BIM professional to create owner-inspired models suitable for facility management purposes. The interviews verify that construction firms are faced with challenges when attempting to meet the needs of facility owners. This thesis presents the obstacles that industry professionals are facing in meeting client needs in respect to BIM for use during facility management. This thesis also discusses processes that firms are using to turn over

models to owners and outlines a purposed process for the creation of owner-inspired models by contractors.

DEDICATION

To my loving wife, Holly Brooks, for her unwavering patience, support, and encouragement.

ACKNOWLEDGEMENTS

The process of conducting this research has been a long road of challenges and lessons learned. I would not have made it, if not for those who helped me along the way. I would like to express my sincere appreciation to my advising committee, Dr. Shima Clarke, Dr. Dennis Bausman, and Dr. Jason Lucas. They kept me focused on the goals of the research and provided mentoring and constructive criticism to help arrive at a better product. They shared their wealth of knowledge and experience for which there is no replacement.I offer a special thanks to my advisor, Dr. Jason Lucas, for his extensive help throughout the research process. He helped me to navigate the intricacies of the research process and pulled me out of the weeds on multiple occasions. His BIM expertise and research experience proved invaluable as he pushed me further than I could have gone alone.

I would like to thank the College or Architecture, Arts and Humanities and the Department of Construction Science and Management for the funding they provided that allowed the required travel to complete the research. I want to specifically thank Dr. Roger Liska and Mrs. Deborah Anthony for helping navigate all of the administrative hurdles I have encountered along the way.

Finally, I want to thank my wife. She provided the strength I many times lacked and offered encouragement when I needed it most. Her sacrifices and patience did not go unnoticed, and for this, I will forever be in debt.

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Chapter 1: Introduction

1.0 Introduction

The growth of Building Information Modeling (BIM) suggests it is quickly becoming the standard for design, preconstruction, and coordination activities in the architecture and construction industries (Berstein, 2012). Large property owners are becoming increasingly aware of the benefits of using BIM in comprehensive facility management plans and requiring BIM use on their projects (Howard & Bjork, 2008). This research looks at how BIM is being effectively used by industry members in an effort to extend the use of virtual models to facility management. BIM is more than a simple 3D model, it allows for the creation of a model that extends to activities throughout the entire construction process and facility life cycle (Eastman et al, 2011)

Building Information Modeling has numerous benefits to owners during and after construction, but has generally proven to be most beneficial in implementation by larger owners capable of investing resources into the creation of a model (Sabol, 2008). The owners characteristically have a large portfolio of facilities, and the facilities themselves are typically more complex (Azhar, Khalfan, Maqsood, 2012). The uses of BIM by owners are numerous but generally fall into one of four major groups including facility maintenance and scheduling, analyzing facility systems, asset management, and space management (CICRP, 2013). A study by Becerik-Gerber, Jazizadeh, and Calis (2012) provided a list of more specific and common BIM needs that owners are currently or are intending to use models to fulfill. The common uses by owners of BIM are listed below.

This research submits that these represent some of the benefits of BIM, and that if models are developed with owners' end use in mind, BIM utilization could be more approachable for more owners.

1. **Locating Building Components** within the model that are often hidden behind finishes in the facility.
2. **Facilitating Real-Time Data Access**, utilizing the model as a comprehensive data-access point for multiple databases.
3. **Visualizing, Marketing, Planning, and Feasibility Studies** for renovations and demolition by using BIM to locate building components, access historic material information, and assess the aesthetic and structural feasibility of proposed changes.
4. **Checking Maintainability** by utilizing BIM to inspect the accessibility of components, material specifications, and original installation details.
5. **Creating and Updating Digital Assets** during design and commissioning of the project and housing the owners' required information in the model instead of across multiple databases.
6. **Space Management** by using BIM to visualize a space and its attributes such as size, seating volume, and equipment, allowing the owner to more efficiently use the spaces.

7. **Emergency Management**, utilizing the spatial nature of the model for emergency planning and by the responders during an emergency to assess access points, plan evacuations, and pin-point security threats.
8. **Personnel Training and Development** by using a model to familiarize individuals with new facilities, renovation changes, assigned work zones, and boundaries.

This research defines BIM in two parts. First, BIM (Building Information Modelling) represents the process of developing a computer-generated model to simulate the planning, design, construction, and operation of a facility (NIBS, 2012). Secondly, this process ultimately leads to the production of a Building Information Model, or BIM. This model has potential for use by facility owners in long-term facility operations and maintenance (CICRP, 2013). This research explored the current uses of BIM in the construction industry and its potential for application to facility management and the design of a conceptual process to aid in the creation and turnover of complete owner inspired models. This general process allows the development of a model that can serve throughout the facility lifecycle, providing a management tool that can ultimately aid in facility utilization at ultimate performance and efficiency.

1.1 Research Problem

Currently, BIM most commonly finds a home in the offices of architects, designers, and engineers, with acceptance coming more slowly in construction offices (Azhar, Hein, Sketo, 2008). It is being used for the development of facility concepts and for supporting processes during the implementation of a construction plan. The problem is that, while the software and processes for using BIM are accepted in its current arenas, facility managers and owners still face barriers to adopt its use.

1.11 Barriers to BIM adoption in Facility Management Programs

The process of implementing BIM in facility management will create initial demands on personnel, likely requiring a designated individual or team for implementing the new facility management tool (CICRP, 2013). The technology to operate BIM is becoming increasing available but barriers to effective use are created by technology interoperability issues that could arise and the financial investment that will likely be required (Azhar et al, 2008). The existence and severity of these barriers ultimately depends on a coordination of organizational goals, culture, structure, and established processes (PMI, 2008).

A model contains a vast amount of information, and this information creates two challenges that owners must be aware of and take measures to avoid. The first complication using BIM is the validity of the data contained within the model (Azhar et al, 2008). Current literature indicates a large degree of ambiguity concerning who is responsible for the validity of the information and the risk associated with this responsibility (Singh, Gu, Wang, 2011). The second challenge created by the model data concerns the proprietary nature of the information contained in the model, between vendors, designers, contractors, and the owners (Azhar et al, 2008). Owners and contractors alike should, by whatever legal precaution necessary, ensure that the information contained in the model be used appropriately in respect to guidelines placed on it by the contributors (Thomson, 2001).

The barrier most relevant to this research is the gap in model usefulness resulting from a lack of owner involvement in the model's creation (Liu & Issa, 2013). Owners' limited knowledge of BIM is directly tied to their lack of involvement in the creation of facility models (Becerik-Gerber et al, 2012). Owners' informed participation is essential for the creation of a model that contains information tailored to meet their specific needs. The current literature surrounding the standards for BIM development does not suggest a method for easily creating owner inspired models. One of the first steps to making BIM more useful to owners is to create models that represent owners' needs and begin bridging the gap in functionality created by a general lack of knowledge (Liu & Issa, 2013).

1.2 Research Objectives

The main goal of this research is to develop a universal, systematic process for the creation of meaningful models during construction that support the owner's needs during post-construction activities turnover of the model to owner.

The objectives of this research are laid out below. The first objective *(Identify Successful Practices)* together with the second objective (*Develop Process),* lead to the third objective (*Information Verification).*

Objective #1: Identify successful implementation practices of BIM in facility management.

This objective aims to identify current industry practices that are supporting the creation of models which meet the owners' facility management needs. This objective will determine, through literature review and case study analysis, what some of the common problems contractors face when developing a model for an owner are and what types of information owners are requiring in models to operate facilities.

Objective #2: Develop a conceptual process for owner-facilitated BIM creation and contractor-to-owner model turnover.

The second objective is to create a general process that makes the task of utilizing BIM and turning it over to the owner more approachable and user-friendly for contractors. This conceptual process for BIM creation is intended to help owners and contractors understand the potential for BIM use in facility management and provide a tool for arriving at the creation of a model that meets owners' management needs at just the right level of detail. The general process is supported by worksheets that when used assist the contractor and owner identify the LOD and attached information needed in the model. For the purposes of this study, a worksheet that details the tasking, level of detail and recommended non-graphic information will be fully developed for commercial

HVAC in order to demonstration its function. Future research will expand the framework of worksheets to include all building elements as defined by Uniformat.

Objective #3: Verify process and worksheet information through member checking.

The general process and information contained in the initial worksheet is presented to industry professionals (BIM Designers/Managers) to gather their feedback and input on the accuracy of information links to LODs and non-graphic information in the worksheet and its application within the general process.

1.3 Methodology

In order to reach the objectives of this research, various research methods are used to collect, analyze, and organize the data. The preliminary research took the form of an in-depth literature review of current and historical studies regarding the use of BIM in facility management. The literature review set the form for which the study would proceed in analyzing BIM-enabled facility management practice. In an effort to get detailed information on successful BIM creation and implementation strategies, case studies were utilized. Industry members that were identified as having advanced experience with BIM and providing a model turnover were asked to participate in case study interviews. The case study interviews were used to develop case studies that were analyzed for commonalities. As a result of the case studies and literature review, possible uses and needs for an owner-inspired BIM were identified and served as the basis for creation of the conceptual general process and worksheet in Objective 2. The worksheets and process were then verified in Objective 3.

1.4 Research Limitations

The initial limitation of the study is that it was generally limited to examining firms in South Carolina, North Carolina and Georgia. This limitation was created by the constraints of time, scheduling, funding, and travel. In-person interviews were chosen above phone interviews for several reasons. The intimate nature of in-person interviews allowed for the evaluation of the respondents' BIM creation documents and resulting models. The in-person interviews allowed for greater control over the questions and allowed for more in-depth answers than may have been received over a phone or other digital format. An effort was made to select construction firms and facility owners that are currently providing models and using BIM as part of a facility management plan but that were within close geographic location to Clemson. The firms selected were generally larger in nature, averaging 400 million dollars a year or greater in revenue and specialize in complex facilities such as healthcare and datacenters. The owner that participated in the interviews manages over 400 facilities and has an advanced facility management department. These constraints lead to a purposive sampling, two of the Clemson University department of Construction Science and Management Corporate Partners and a healthcare owner located in nearby, Charlotte NC. The research interviews were controlled by the participant's availability for an interview, willingness to share their practices, and experience level of the firms interviewed. Though very notable and progressive firms were interviewed as case studies, time and geographical locations placed boundaries on the extent of the research and the type of information that was shared. The framework is currently limited by only being fully developed for HVAC services but will be expanded for all building components in future research. The information contained in the worksheets and the proposed general BIM creation process were evaluated for the accuracy of the information and the feasibility of implementation based on the opinion of seasoned industry member. The process and framework have not been evaluated in practice, and this will be an essential part of future research.

1.5 Organization of Content

This thesis contains Literature Review, Research Methodology, Framework Development, Findings and Validation, and Conclusions chapters. Chapter two, the literature review, is a comprehensive view of current and historical studies of BIM use in facility management while encompassing major works that serve as guides for BIM use and development. Chapter three, the research methodology, provides a detailed explanation of the methods used to conduct the research, including the case study development and analysis. The framework development mentioned in this chapter are expanded upon and described in chapter four. The findings and framework validation, including an explanation of the framework are explained in chapter five. Finally, chapter six explains the limitations of the study and the conclusions of the study along with final thoughts and suggestions for future research.

Chapter 2: Literature Review

2.0 Literature Review

There are numerous applications for Building Information Modeling across the Architecture, Construction, Engineering, and Facility management disciplines with endless literature on the various applications. This literature review selected literature that cultivated and influenced this research. The current literature was explored to establish the context of the research and is broken into the sections below.

2.1 What is Building Information Modeling?

2.2 BIM Applications in the Construction Industry

2.3 Benefits of BIM in Facility Management

2.4 Limitations of BIM Use in Facility Management

2.5 Why Aren't More Owners Using BIM in Facility Management?

2.1 What is a Building Information Model?

Virtual design in the AECFM industries has been traditionally dominated by computer-generated models created using the CAD platform (Sabol, 2008). CAD models are typically relatively simple geometric representations of buildings that are often 2D but can be 3D (Sabol, 2008). The lines, arcs, and geometric shapes of CAD are steadily being replaced by the smart components of BIM. Building Information Models are created by an arrangement of predetermined, fully customizable building components such as beams, walls, windows, columns, mechanical equipment, or even landscaping elements. These elements then carry with them a link to detailed information concerning the specific component such as material quantities, cost estimates, and schedules. The attachment of data to building components creates a model with limitless information, often considered n-dimensional with the capability of housing many layers of information (Azhar et al, 2008).

It is important to distinguish between a Building Information Model and the process of creating the model which is referred to Building Information Modeling. Pennsylvania State University's *Planning Guide for Facility Owners* defines the process of modeling as "The act of creating an electronic model of a facility for the purpose of visualization, engineering analysis, conflict analysis, code criteria checking, cost engineering, as-built product, and budgeting" (CICRP, 2013). The process and the product of the process are two distinct entities but there is a gap that presents itself in between the two in terms of facility management. This shortcoming is being fueled by the increased demand by owners for BIM technology to be used on their projects, but many owners do not know what components they need in a model or if their contractor is capable of delivering it (Mayo, Giel, Issa, 2012). This gap is the main problem this research aims to bridge, the solution being a system for ensuring the modeling process results in a product that is useful past the completion of construction.

2.2 BIM Applications in the Construction Industry

The adoption of new technology is usually a slow process, and this was no different for BIM adoption in the construction industry (CICRP, 2013). In order for new technology to be a viable tool in any business, it must be practical, functional, and ultimately, profitable. The first and perhaps most obvious use of software that can produce virtual construction models is the production of visuals, and BIM accomplished this like its predecessor, CAD (Azhar et al, 2008). As a visual aid, the models serve as a design and most importantly as a sales tool for the contractors (Azhar et al, 2008). The model allows all users and stakeholders to obtain a better understanding of the proposed project and establishes more concrete expectations (Azhar et al, 2008). The research is not claiming that building information models are reinventing virtual models as a visual tool, but reveals that BIM offers contractors advantages that past modeling software just simply cannot achieve in a meaningful way.

One of the leading challenges of any major construction project is the coordination, assimilation, and validity of information. There is information concerning every component and process that is involved in a construction project.. A Building Information Model is created in a way that allows essentially all types of information to be linked to respective building components (Sabol, 2008). This information linkage creates an organized, user-friendly interface that allows information to be extracted quickly and efficiently. Information accuracy has implications throughout the construction process, especially in the execution of work and the project timeline. The information linked to a model is useful in collaborative planning and coordination of the construction trades, forcing the users to work together to solve clashes before the work is performed. It seems almost intuitive that the utilization of data-rich project models would be attractive to potential users, namely construction firms. The streamlining of information coordination efforts improves the ability of contractors to validate and share information to many potential users (Azhar et al, 2008).

In recent years BIM utilization has grown immensely among construction firms. Survey results published in McGraw Hill's 2012 Smart Market report stated that in 2007, only 28% of US construction firms were utilizing BIM on their projects but this number grew to 71% by late 2012 (Bernstein, 2012). The reason behind this strong growth can be linked to the increased availability of the software, the increasing number of people who have the skills to use it and most importantly, the business benefits it offers contractors (Bernstein, 2012). Stanford University's Center for Integrated Facility Engineering (CIFE) revealed in a 2007 report that using BIM on projects reflected in several measurable ways. CIFE reported that projects that utilize BIM are witnessing an average of 40% reduction in unbudgeted changes, experiencing cost estimates that are accurate within 3%, utilizing clash detection to avoid rework at rates up to 10% of the total project value, and cutting the project time by an average of 7% (CIFE, 2007). These benefits are all measurable on the bottom line, fueling the rise of BIM in becoming the standard for project modeling in the construction industry (CICRP, 2013).

2.3 Benefits of BIM in Facility Management

As explained above, contractors are reaping numerous benefits from the use of Building Information Modeling throughout the design, commissioning, and construction of projects. It stands to reason that many of these same BIM uses would translate into practical benefits for facility owners. It is typical at the end of a construction project for the owners to receive numerous boxes of documents pertaining to all aspects of the facility from equipment specifications to as-built drawings, but is information delivered in this way as useful as it could be? (East, Brodt, 2008). Like the benefits that are important to contractors, the benefits most important to owners make the management of information easier and more reliable, create data-rich visual tools for facility planning and maintenance, and of course are friendly to the bottom line. Owners are seeing benefits even from the earliest phases of facility conceptualization and design that carry through to facility turnover and into the management of the facility. The current perception in the construction industry is that the use of BIM will result in more successful, better organized projects, and this perception is transcending to facility owners (Mayo, Giel, Issa, 2012).

A facility management plan is essentially an elaborate information management system utilized to complete the necessary processes to maintain the integrity and usefulness of the building. These processes typically include facility maintenance activities, space management, asset management, and strategic planning (CICRP, 2013). The information required to efficiently manage a facility is fairly extensive including as-built drawings, shop drawings, material specifications, contracting documents, equipment warranty information, maintenance schedules, start-up reports, equipment locations, work orders, and building area layout/zoning boundaries (Becerik-Gerber, Jazizadeh, Calis, 2012). As earlier mentioned this information is often handed over from the contractor to the owner in boxes, files, and sometimes disks, depending on the format (East, Brodt, 2008). The process of changing or organizing this information into a useable format is a time-intensive and expensive procedure, and sometimes it is simply left in the box and stored in a closet somewhere until it is needed.

The ability of a Building Information Model to host linked facility information makes it unique from past virtual models. This ability reaches further than just retrieving the information to perform routine facility tasks and gives BIM the unique ability to be a part of a larger facility management plan. The visual linkage of information in a model assists in creating the multidimensional model that makes it so useful. This information and associated visual can be tied to other facility management tools such as COBie, a facility management tool that offers facility information mostly through images of paper documents (East, Brodt, 2008). The linkage of current facility management programs such as COBie may still include images of paper documents but would be linked to a virtual representation of the respective facility item inside of a BIM. COBie stored facility data is missing critical information that is pertinent to those maintaining the facility. In a BIM integrated facility management program, the facility manager would not only have access to the information linked to a certain facility element but could view linked facility components, systems, dimensions, and relationships (East, Brodt, 2008).

Owners are becoming increasingly aware of the benefits of purposeful facility management, ultimately reflecting on their bottom line.

The ownership of a facility is expensive. The costs begin at conceptualization and design and continue to ultimate facility disposal. The design, construction, and purchasing of a facility is relatively quite low considering the life-time costs the facility is likely to incur. A 2010 study by the National Institute of Building Science stated that the initial costs, defined as the purchase, acquisition, and construction of a facility, only constitute two percent of the total life-time facility expenses. The bulk of all expenses of a facility occur in the energy usage, operations, maintenance, and repairs costs (Fuller, 2010). The NIBS study indicates that these expenses constitute a colossal six percent while the remaining ninety-two percent is the cost of personnel. The reality is that the facility phases following construction are by far the most expensive (Fuller, 2010). The maintenance and operations alone incurs three times the expense of the initial construction costs according to the NIBS study. A Building Information Model has the potential to improve the facility management plan and theoretically decrease the costs of every facility expense. The use of BIM has been shown to decrease construction expenses due to clashes by up to 10% (Azhar et al, 2008), ease the burden of information management and reduce personnel hours required (Mayo et al, 2012), model energy uses (Becerik-Gerber et al, 2012), and provide all the necessary information for more efficient performance of maintenance and repairs (Becerik-Gerber et al, 2012).

2.4 Limitations of BIM Use in Facility Management

Although it is proving to be useful, BIM does not come without limitations that must be considered. The first and perhaps most discussed limitation is that a BIM can come in many forms, in various types of software. This variety of platforms for a BIM, coupled with the extensive variety of facility management systems (FMS) creates problems of interoperability (Taylor, Bernstein, 2009). The lack of software interoperability can prevent the transfer of information from one person or organization to another because of the use of different types or versions of modeling software, placing a strain on the value of collaboration (Becerik-Gerber et al, 2012). This interoperability issue is a recognized problem among construction industry professionals who are placing pressure on software developers to create platforms capable of overcoming this obstacle and allowing users to reap the most benefit from shared information (Grilo & Jardim-Goncalves, 2010).

Beyond the technical limitations of building information modeling, there are practical business confines. The 2012 McGraw-Hill smart market report indicates that many contractors perceive that there is not enough demand by owners to invest in the technology. However this could also be interpreted that owners who use BIM are dealing primarily with BIM knowledgeable designers and contractors. The expense of the technology is another important limitation to adoption of BIM (Bernstein, 2012). The initial investment required for the technology, including the software, robust hardware required for running a model, and personnel training present a sticker-shock that can be off-putting to many potential BIM users (Berstein, 2012). The costs of implementing

BIM technology could be overcome by potential savings due to increases in efficiency and reduction of rework but there have not been sufficient case studies conducted to reflect positive return on investment (Becerik-Gerber et al, 2012).

Many potential users have the perception that current practices are more efficient and practical than BIM-assisted practices (Bernstein, 2012). Though this is a popular perception, generally this argument is weakening as the technology becomes more capable and accessible (Bernstein, 2012). This position held by some non-users could be the result of a lack of education on the capabilities (Becerik-Gerber et al, 2012). The 2012 Smart Market Report noted that even though contractors are adopting BIM at the highest rate (74%), one in five contractors do not understand what BIM is or its potential applications.

2.5 Why Aren't More Owners Using BIM in Facility Management?

This perception of improved project outcomes with fewer changes and conflicts is resulting in more owners asking for BIM to be used on their projects and impacting their decisions in selecting contractors. This perception of improved projects is encouraging more and more facility owners to demand that BIM be utilized on their projects (Mayo et al, 2012). A 2008 study by McGraw-Hill construction consisting of a nation-wide survey indicated that forty-six percent of owners have used BIM on one or more projects with only thirty percent of owners consider themselves to be "heavy users" (Jones, 2008). It can be assumed that this number has increased with the development and wider availability of BIM software. It is logical that owners, who arguably have the most benefits to gain, would be driving the use of building information modeling.

A perception of BIM benefits by owners is accompanied by a perception of difficulties associated with the adoption of a BIM integrated facility management plan. The process of transferring facility information to the owner is a historically difficult process and obstacle for owner use of BIM in facility management (Mayo et al, 2012). Any technology, BIM included, is often met with financial and cultural boundaries when it is considered for implementation within an organization (PMBOK). The inclusion of BIM as part of a facility management plan requires an investment by the owner into education, personnel, technology, and of course, financial resources. The financial investment to adopt BIM varies greatly as the technology is continually changing and evolving, creating even further resistance. (Becerik-Gerber et al, 2012). The cultural component of BIM resistance is dependent upon each individual organization and the value the organization perceives from the adoption of new technology (PMBOK).

Many owners feel as though they simply are not knowledgeable about BIM, its benefits, and the adoption process (Becerik-Gerber et al, 2008). Many owners are not familiar with the capabilities of BIM and therefore do not attribute a high intrinsic value past the construction phase. Many owners are unsure of the information or deliverables they need from a model to adequately support their facility management needs (Mayo et al, 2012). The Levels of Development established by the BIM Forum create specifications of detail for BIM models for certain aspects of a facility (BIM Forum, 2013). Though these LOD's are very specific, they are written for understanding and use by architecture, engineering and construction professionals (BIM Forum, 2013). The missing piece here that leaves owners in the dark is the process of identifying what level of detail they need for their unique facility to meet their unique needs. The lack of owner knowledge and contractors' difficulty in providing a BIM capable of meeting owners' needs is the gap this research is addressing.

Chapter 3: Research Methodology

3.0 Research Justification:

This is a pragmatic study to explore successful applications of BIM to the management of facilities in an effort to identify successful implementation strategies. The implementation strategies explored by this research refers to the processes used by the interviewed firms to create models that meet the needs of their clients. Though the literature search identified bodies that are creating standards for BIM, such as the BIMForum, there was no standard process identified for which firms can use in the creation of models that reflect the needs of the stakeholders. This lack of a documented, established process indicates that firms are relying on their experience and internally created methods for arriving at complete BIM models. The process identified for each case study firm will be represented in the “data display” section of this chapter. These strategies, reasoning, and accompanying barriers to implementation identified through the case study interviews will serve as the basis for the development of a more general process that can be tested and later implemented by other contractors. Though this general process is intended for contractors with less experience with BIM, it could be used by contractors that have the need for creating an owner inspired model.

3.1 Research Design:

The stage was set for the research by conducting an intensive literature review on topics surrounding BIM use in facility management and construction. The literature search yielded numerous articles and various noteworthy works that are establishing the standards for BIM use industry wide. Prominent worksestablishing these standards include Penn State's ”BIM Planning Guide for Facility Owners”, McGraw-Hill's “The Business Value of BIM in North America: A Multi-Year Trend Analysis and User Ratings (2007-2012)”, BIMForum's “2013 Building Information Modeling LOD Specifications, and various works by Salman Azhar a professor at Colorado State University. These notable works along with the numerous supplementary articles shaped the direction for this research and serve important roles in the creation of the process framework.

As stated in the previous section, this research is interested in identifying the processes that construction firms are using to create models for their clients. For this reason, a qualitative research method was selected. The qualitative case studies will allow for a detailed look into the processes being used by the selected case studies. Qualitative research allows for the identification of events and actions that contribute to a process, this is simply not a strong point of survey or experimental research methods (Maxwell, 2005). Quantitative methods have their place in the future research in measuring the extent of effectiveness of the final process and interface that will be developed. This phase of the research however, is identifying what these processes are and how they can be utilized by others, resting firmly in the qualitative realm of research (Maxwell, 2005).

3.2 Primary Data Collector:

Exploratory Case Studies

The utilization of case studies allowed the research to take an in-depth look at the processes being used by the selected participants. The cases studies took place to describe the processes being used by each of the firms and to compare the processes for similarities. Similarities in the process will indicate that the process is working for the various firms, each with their own unique demographics and working conditions. The processes with noted similarities and differences are noted in the data display section of this chapter.

The case studies for this research are considered to be exploratory because they are setting the stage for broad yet intensive future research where both the process and accompanying worksheet will be developed and tested on a larger scale with a larger variety of contributing firms. This research is setting the baseline for the future research and creating a place from which questions can be generated to further the research (Colorado State Case Studies Writing Guide, 2012).

3.3 Sampling Design and Data Collection:

The study utilized a combination or mixed purposive sampling method (Creswell, 2007). The mixed purposive sampling method allowed for the selection of firms that were within a two hours' drive to Clemson, South Carolina. The convenience of the geographic location of these firms made it possible to conduct the in-person interviews with-in the time limits of the research. Twenty-one construction and construction related firms, scattered across the southeast expressed interest in participating this in this study. While interested in participating, many of the firms had been exposed to Building Information Modeling, but did not have significant experience using models on projects. Seven of the twenty-one firms had experience using models on construction projects, but the extent of this experience was uncertain. In an effort to ensure the information received from the firms was of high quality, several benchmarks were set. First the firms had to have experience creating models for use by a facility owner. This required that the participating firm have designated staff or a department devoted to creating models.

The point of contact and unit of analysis for this research was the director of the BIM creation operations at the respective firms. To further ensure that the information received from these BIM directors was of high quality, several requirements were established. First the directors had to have formal education related to building information modeling and construction processes. This education requirement had to come in the form of bachelor's degree in construction science and management or architecture. After considering all of these requirements, two contractors and one owner were asked to participate in the research as case studies.

In-person interviews were selected because each of the participants had a short presentation of their BIM utilization practices. The presentation included visuals and descriptions of the projects where the firms' BIM utilization had been most successful. Beyond the presentation, the in-person interviews created an intimate, mutually beneficial setting where information could be shared that met the needs of all involved both the participants and researchers (Creswell, 2007). The independent case studies were conducted with independent firms that varied in nature. The firms varied in size, metropolitan location, geographic reach, typical project size and type, and in the stakes they held in the creation of a BIM (Two contractors, one owner). The details of each participant can be found in the following section. In each case study the end goal was to identify the process they use to create models that can be used by owners for facility management purposes. The variety in the firms operations, size and model related interest contributes to the validity of the information gathered. The firms have each independently created their own process for creating models. This triangulated approach allows for the analysis and comparison of three, independently created processes that may have similar approaches to creating models that could have applications for other contractors and owners.

The data collection utilized for this study takes the form of semi-structured, personal interviews that revolve around the list of questions listed below. The interviews all take place at the office of the respective firms and, as mentioned, include a short presentation by the interviewee reflecting their application of BIM on current and past projects, and their methods for creating the models.

3.31 Interview Questions

1. Establish the interviewees role at the firm in BIM development and application
2. Identify the process by which the firm develops or acquires a model
    a. Are project models typically developed in-house or produced by a third party?
3. In what ways does the firm utilize the model and what kinds of benefits are gained?
    a. Any Notable reduction in rework / clash detection, material acquisition, coordinating materials or systems
4. Identify barriers to facility owners using BIM
5. How is the owner involved in the creation of the facility model?
    a. When does the owner become involved?
6. Identify what owners typically require in a model
7. How do you think the model could be used in facility management?
8. Are owners using BIM as part of a facility management plan and how are they using it?
9. Has your firm turned over a model to owners and what is the process for the turnover?
10. What is the best ways that BIM could be integrated into facility management?
11. How does the barriers and costs of using BIM compare to its benefits in a facility management setting?

3.4 Case Studies and Unit of Analysis:

The case studies were not chosen based only on their geographic location to Clemson University. The firms selected had to meet a set of criteria that made the information gathered from each case study valuable. At each firm, the interview was conducted with the director of the BIM department (unit of analysis).

3.41 Case Study 1: Large Contractor

The first case study took place with a large contractor head quartered in Atlanta, Georgia. The firm is reported to have had $1.757 billion in revenue by Engineering News Record in 2013. The firm was established in Atlanta in 1960, but over the past fifty-four years the firm has established a national reach with satellite offices across the country including offices in Charlotte, Dallas, Washington DC, Phoenix and San Jose. The firm prides itself in the construction of large, complex and often high profile projects. These projects include corporate headquarters high rises, extensive data centers for companies such as Apple®, Master Card® and American Express®, aviation projects including several international airports, advanced higher education facilities, luxury resorts, and currently the firm is the lead contractor on the New Georgia Dome in Atlanta. The firm works on both public and private projects, but most of their projects fall in the private realm. These projects are generally accomplished by a range of methods that typically fall within either a construction manager at risk or design-build delivery method. It is important to note these delivery methods, because these methods typically include heavy involvement of owners, and magnifies the importance of creating models that meet the needs of these involved owners.

The formal BIM department at this firm was established approximately ten years ago. The current director of the department helped to establish the department upon his arrival to the firm and has served as the department director from beginning. The department director has a degree in construction science and management, and is actively involved in the BIMForum. He submits articles to the BIMForum and has lead online BIM workshops through the BIMForum, helping others learn the capabilities of BIM. It should be noted that the BIM department at this firm considers itself to be a leader in BIM utilization in the industry. The firm has designed and built their own unique BIM software suites that conform to their needs and the needs of their clients and sub-contractors. Though unique to this firm, the software they have created has been crafted in such a way to avoid interoperability issues with off-the-shelf software that is likely being used by owners, other contractors, designers and engineers. The BIM director mentioned that the firm has begun utilizing BIM in some fashion on most projects, regardless of project size.

3.42 Case Study 2: Medium Contractor

This medium sized contractor located in Charlotte, North Carolina brought in $399 million in revenue in 2013 according to Engineering News Record. This firm was founded in 1963 and is headquartered in the greater Charlotte, North Carolina Area, with a secondary office in Raleigh, North Carolina and has recently established a regional office in Greenville, South Carolina. The firm typically works within a regional reach of the Charlotte office, but the firm's healthcare expertise demanded the creation of the Raleigh and Greenville offices they pursue projects with other healthcare clients. Though healthcare is the firm's flagship market segment (60% – 65%), the firm has a diverse portfolio including complex privately and publically funded projects such as advanced higher education science buildings, large sports complexes, high-end senior living facilities, extensive religious facilities, theatres and auditoriums, community recreation centers and cultural centers. The firm typically works within a construction manager at risk delivery method, but often is forced to hard bid publicly funded projects.

Similar to the previous case study, this firm participates in more complex projects with involved owners. These two variables play a pivotal role in the effort the firm has placed in developing their BIM department and procedures. The owners they typically work with are asking for BIM to be used on their projects and show interest in using it for facility management purposes. Following the increased demand for BIM usage by owners, the firm began the development of their BIM department in 2006. Soon after the development of the BIM department of one person in 2006, the firm recruited an architect to become the manager of the department. This manager, who participated in the case study interview, began working with BIM application approximately twelve years ago and has a bachelor's degree in architecture. The manager is a member of the BIM forum and routinely attends their conferences. The firm's BIM department has grown from one to seven members over the past eight years including two architects, three engineers and two detailers.

3.43 Case Study 3: Large Facilities Owner

The third case study took place with a large, advanced owner. This healthcare organization was first established in 1943 in Charlotte, but has grown to service the breadth of North and South Carolina over the past seventy years. The firm operates on a $7.7 billion annual budget, servicing over 8,000 patient beds in addition to numerous outpatient care centers. The healthcare provider has 437 facilities, including emergency care, multiple children's' hospitals, cardiology centers, oncology centers, medical research facilities, education departments, and multiple specialty centers.

As one may imagine, this extensive portfolio of complex facilities creates a substantial maintenance undertaking for the organization. The organization began with a basic maintenance department and physical plant. The expansive and rapid growth of the firm demands extensive organization and the firm began using virtual models of their new built facilities in the late 1980's. The firms' rapid growth rate created the need for construction and in doing so the firm became familiar with the capabilities of BIM in the early 2000's. As the firms' confidence in BIM increased, a BIM department was created as a branch of facility management.

The BIM department has no official beginning time but was a gradual process that evolved over time. The current director has been in her current position for just over 5 years and has a bachelor's and master's degree in architecture. The owner has progressed to the point of requiring contractors to provide a BIM model for every new project. These models vary in complexity, being facility specific and reflecting the intended uses of the model. At the point of the interview the organization had begun retroactively modeling facilities within their portfolio that were built before the technology was available. The retroactive modeling is limited in that not all information is available, making the uses of the model limited. The BIM Manager stated that at the time of the interview, the firm has models created for approximately 80% of their facilities, and intend to progress until all facilities are modeled.

3.5 Data Display:

The data from the interviews are represented below in a question-answer format with the above interview questions serving as the basis for organization. Commonalities among firms are noted and represented graphically as part of the data analysis. Each case study will is presented with a brief summary of the study that notes their methods, barriers they are currently facing and the commonalities to other firms' processes. The processes from each interviewed firm will is represented in a standardized graphic format to show the steps the firms take to create a model. The process graphics will be compared.

3.51 Case Study 1 - Large Contractor: Interview

1. Establish the interviewees role at the firm in BIM development and application

   Response: Interviewee is director of the firm's BIM department. The interviewee conducts owner and subcontractor conferencing for model creation and has led the development of the firm's BIM creation process.

2. Identify the process by which the firm develops or acquires a model

   a. Are project models typically developed in-house or produced by a third party?

      Response: The models are created internally by the in-house BIM department. Typically, models are created by combining models from subcontractors, architects, and engineers. The firm "meshes" the models together and ensures completeness and interoperability.

3. In what ways does the firm utilize the model and what kinds of benefits are gained?

   a. Any Notable reduction in rework / clash detection, material acquisition, coordinating materials or systems

      Response: The firm uses models first for a visual for the owner. Visualization of the facility before construction informs the owner of what to expect and the ability to make informed project changes in a relatively penalty free atmosphere. Beyond visualization, the firm uses the model as the primary mode for logistical coordination between trades and vendors, to detect system clashes in the facility, and for the organization or building documents and extraction of material quantities during procurement. The interviewee noted that the firms advanced use of BIM and the ability to create complex models is a major selling point to prospective clients.

4. Identify barriers to facility owners using BIM

Response: The participant identified two major barriers to the use of BIM by facility owners. The first barrier is that the owners simply do not know what BIM is and the capabilities of the technology. The second barrier is that owners may know what BIM is and even understand the capabilities of the technology but they do not know what they need in a model to make it most useful. The firm stakes the time to understand what owners need in a model through an execution process they have developed over the past 10 years. The process is still tedious and is comprised of paper based checklists. Often, owners are unaware of what they can use BIM for and take one of two routes. The owner may simply elect to not have the model customized to meet their needs, or opt to have every part of the model developed to its full capacity. The first option of minimal development is likely to result in a model that does not meet the needs for facility management tasking. The second alternative of full capacity development, often results in a model that is cumbersome, difficult to maintain and its costs outweigh its benefits. Though many owners fall into one of these categories, there are a select few advanced owners that know what they need in a model and give the firm specifications to follow for model creation.

5. How is the owner involved in the creation of the facility model?

    a. When does the owner become involved?

    Response: Owner involvement in the model creation process generally begins at conceptualization. If the owner is not educated and involved in the process early, it will result in a model that does not fully reflect the owners' needs. Late involvement can often result in numerous modeling and facility changes if issues are not dealt with in the early stages.

6. Identify what owners typically require in a model

    Response: There is no typical requirement for an owner. It heavily depends on the facility type, the degree of technology use by the owner and what the owner's intended uses are. This uniqueness that comes with each project is why the process of analyzing owner needs so tedious. While the firm has created processes for BIM execution, the process often has to be tailored to meet uniqueness of the owner.

7. How do you think the model could be used in facility management?

    Response: The benefits of BIM for owners are very similar to the benefits seen by contractors. Many owners are bringing to use models for space management, the organization of documents, and as a data base for detailed facility information. Many owners are supplying the model to the maintenance departments, where it is being used to navigate complex facility systems when planning for system repairs or renovations.

8. Are owners using BIM as part of a facility management plan and how are they using it?

   Response: While some owners want the model just for their records, many are using it as part of a facility management program. Most clients this firm works with are using it in conjunction with a facility management program already in place and to complement a system such as COBie or Archibus. The pairing of the systems allows for large amounts of information to be extracted from a model and saves the cumbersome task of collecting data for a facility management program.

9. Has your firm turned over a model to owners and what is the process for the turnover?

   Response: The firm has regularly provides models to owners. Advanced owners typically have a process for integrating the model into a predetermined facility management program and need little help from the contractor. Many owners that are just beginning to use BIM for facility management purposes need more assistance from the contractor. This assistance may come in the form of education and technical support or as a complete facility management program development.

10. What are the best ways that BIM could be integrated into facility management?

Response: A model is all about information, data is the most important component but graphic information is also important. The most practical application of BIM to facility management programs is to use it as comprehensive source for facility data. This data can be stored in BIM and accessed by other applications. Owners often have a hard time compiling data after construction, but BIM utilization, if done correctly, provides the owner with all information that is needed to manage the facility. Like any facility management program, the information in a model must be maintained to be useful.

11. How do the barriers and costs of using BIM compare to its benefits in a facility management setting?

Response: The usefulness and return on investment for a model is hard to measure and completely dependent upon the owner. The owner's clients that want BIM understand the benefits and have already made the investment required to make BIM a part of their facility management program.

3.52 Case Study 2 - Medium Contractor: Interview

1. Establish the interviewees role at the firm in BIM development and application

   Response: The interviewee serves as the director of the BIM department. Much of his role is to develop models that meet the requirements of construction and the owner. He coordinates the BIM creation process between the designers, engineers and the trades. He stated that a large portion of his job and perhaps the most challenging is conducting conferences with owners to develop a BIM execution plan.

2. Identify the process by which the firm develops or acquires a model

   a. Are project models typically developed in-house or produced by a third party?

   Response: Models are almost always created in-house. The BIM team takes models from the designers, subcontractors and engineers and fuses them into one comprehensive model that is used for construction purposes. The team often has to work closely with these various stakeholders, ensuring clashes are detected early and corrected prior to construction.

3. In what ways does the firm utilize the model and what kinds of benefits are gained?

   a. Any Notable reduction in rework / clash detection, material acquisition, coordinating materials or systems

   Response: The interviewee stated that the biggest benefit the firm is currently seeing from the use of BIM is project coordination. The model provides a centrally located, graphically organized way of sharing data across the various stakeholders while coordinating the construction activates. The coordination benefits everyone by saving time and preventing unnecessary clashes among the various trades.

4. Identify barriers to facility owners using BIM

    Response: The respondent answered this question in a very similar way to the first case study interviewee. As part of his role at the firm, the respondent conducts owner conferencing to determine modeling needs. While the firm has too developed a BIM execution plan, it is fairly simple and just covers the basics. He stated that many times most parts of a model get developed at the same level. This often means that some building components are developed well past where they need to be. This costs time and money, but the firm's BIM execution plan is not currently developed enough to educate the owner on the all of the various components and need for specific levels of development.

5. How is the owner involved in the creation of the facility model?

    a. When does the owner become involved?

        Response: The owner becomes involved in the modeling process very early. The model is not only a tool for construction but also a tool for conceptualization, design, and sales. The firm uses modeling to their advantage as a selling tool, meaning the owner is involved with BIM in some way from the very beginning. He stated that even though the owner gets involved early, the involvement is not always constructive in terms of model development. He stated that sometimes the coordination required to create a model can skip over the owner, and it's not until the model is being created that the team realizes the owner's needs have not been considered. Retroactive changes to make a model meet owner needs are much more difficult, and for this reason the team attempts to get owners involvement early.

6. Identify what owners typically require in a model

   Response: Many of the firm's projects are similar in nature (healthcare), and for this reason the firm has an idea what to include in a model for the needs of the owner. Many facilities are going to have the same basic management tasks, but some owners are more advanced in how these tasks are performed. The requirements of a model depend on the facility and the owner. The firm's typical healthcare clients require that models be to a fairly high level of detail, and represent all crucial systems, especially piping and mechanical systems. The

7. How do you think the model could be used in facility management?

   Response: The respondent stated that this all depends on the model and the information contained within it. The level to which a model is developed and the degree to which non-graphic information is attached to it really determines how a model can be used. He stated that currently most use of models is in maintenance coordination, space management, visualization, and as a way to organize facility information. He went on to say that as models continue to develop that they will be useful tools for such things as energy monitoring and to control automated facility systems.

8. Are owners using BIM as part of a facility management plan and how are they using it?

    Response: The respondent stated that in their experience with owners of complex facilities BIM is being increasingly integrated into existing facility management programs. The owners that they work with are using BIM to locate mechanical systems and components, manage the spaces within a facility, and as a starting point for coordinating renovation planning.

9. Has your firm turned over a model to owners and what is the process for the turnover?

    Response: The BIM department has extensive experience in model turnover. The turnover process is different for each owner. Some owners have a process in place and it is just a matter of transferring the data. Other owners are new to using models and the team has to take on the responsibility of educating owners on what information is contained in the model and how to access it. The firm is hoping to use their BIM expertise as a competitive edge and is looking at offering BIM assisted facility maintenance contracts and serves that include maintaining models for owners.

10. What are the best ways that BIM could be integrated into facility management?

    Response: The model is the best way to visually organize data. The data is tied directly to the model components making it easy to search for and find. It's not a matter of what tasks the model is being used, but rather the degree to which a model is developed. Ideally with a sufficiently developed model, with appropriate non-graphical information, the owner has all the information they could ever need for performing essentially any management task.

11. How do the barriers and costs of using BIM compare to its benefits in a facility management setting?

    Response: The more developed a model is, the more it cost to create. However, the more developed a model is, the greater are its applications. Models have applications for many owners, but the key is to find the balance between development and the owners intended uses. The real barrier preventing the model from being used is lack of knowledge more so than cost. When owners are educated on the benefits of using BIM as part of their facility management plan, the long term benefits of a having a virtual model of their facility is attractive. The construction of a facility is expensive, and with good management the investment can last a long time.

3.53 Case Study 3 – Large Facilities Owner: Interview

* *Some of the questions are changed slightly to reflect an owner's perspective.*

1. Establish the interviewees role at the firm in BIM development and application

   Response: The director of the BIM department has been in her current position with this organization for five years. She has 10 years of experience in using BIM for design facility management. Her education includes both a bachelor's and master's degree in architecture, specializing in healthcare facilities.

2. Identify the process by which the firm develops or acquires a model

   a. Are project models typically developed in-house or produced by a third party?

      Response: The owner requires contractors of new construction to provide a model that meets specific criteria established for the project. The criteria are based on the facility and include expected levels of development for each facility component. The owner has developed a BIM execution plan that is provided to contractors. The specifications for a facility's BIM depend greatly on the complexity and intended uses of the facility. Many of the owner's current facilities were constructed before modeling was available. The firm is in the process of modeling all older facilities, all created in-house.

3. In what ways does the firm utilize the model and what kinds of benefits are gained?

    a. Any Notable reduction in rework / clash detection, material acquisition, coordinating materials or systems

       Response: The firm uses the model as a major component of their facility management program. The model is used as the primary medium for the storage and organization of facility information linked to modeled building components. The model is tied to an Archibus facility management platform. Archibus is used to manage facility tasking and sources its required information from the facility model.

       Beyond organization and storage the firm takes advantage of the graphic nature of building information models. The facilities that have models available use it exclusively for space management. The use of BIM in space management allows the facility manager and space scheduler to view the capacity of rooms, the available equipment and services. This organization is continuously growing and often available space becomes tight. The ability to utilize space in the most efficient way is a significant benefit of having the virtual model.

       As stated, the firm is constantly growing requiring them to find ways to better utilize their space and plan for renovations. The firm uses models to test the feasibility of building renovations. Renovations conducted on the buildings effect the patients, aesthetics of the facility and the work flow of the healthcare professionals. In planning for renovations the firm uses the model to first plan the changes and find alternative designs. After possible designs have been created in the model the design is built as a mock-up inside of a local warehouse. The mock-up is tested by the healthcare providers through various exercises that would normally take place in that space. These trials take place several times and changes are made as necessary. In the end the firm has a visual representation of planned renovations that can be provided to the board of directors, in marketing efforts and eventually provided to contractors for construction.

4. Identify barriers to facility owners using BIM

   Response: The interviewee suggested that some owners that are trying to use BIM but are not gaining a substantial benefit from it are caught in the trap of knowing just enough to be dangerous. The use of BIM requires a commitment to learning its capabilities and developing process for use that work. The director went on to say that the initial investment to use the software comes with a sticker shock, but the owner must become educated on the technology and have a long term vision for its use.

5. How are you involved in the creation of the facility model?

   a. When do you become involved?

      Response: The BIM department is involved in projects from the very earliest conceptualization all the way to the end of construction. The department works with the designer, contractor and facility users to ensure that the model is created in such a way that all relevant information for facility management is included. This has to be done very early in the process to avoid re-working the model or missing out on essential information that may be needed later.

6. What does your firm typically require in a model

Response: Model requirements vary from project to project, depending on the facility and its intended uses. The execution plan that is provided to contractors specifies the level of detail at which each building component must be modeled. This level of detail is determined by the complexity of the building component or system and the tasks that will be involved. The graphic representation of building components is important for certain tasking (space management, maintenance of complex system, renovations), but the information that is linked to these items is even more important. The primary use of the model is to store and organize large quantities of facility information. This information often includes documents such as facility drawings, specifications, material quantities, warranty information, user’s manuals, and replacement or maintenance schedules.

7. How do you use the model in facility management?

   Response: *This question was addressed as part of question 3.*

8. Are owners using BIM as part of a facility management plan and how are they using it?

   Response: *This question was addressed as part of question 3.*

9. What is your experience with model turnover and what is the process for the turnover?

   Response: The owner stated that because they have an established BIM department and extensive experience with BIM the turnover process is little more than the transfer of the file from the contractor. The complete file is transferred to the firm in a compatible format that can be maintained by the owner. The owner stated that less experienced firms would need education in how to effectively use the model and keep it up-to-date. Some contractors that experienced with BIM are offering these services to owners that don't have the resources to keep the models current.

10. What are the best ways that BIM could be integrated into facility management?

    Response: Currently the owner uses its models for space management, facility maintenance coordination, as the main platform for information storage, renovation planning for design and workflow feasibility.

11. How do the barriers and costs of using BIM compare to its benefits in a facility management setting?

    Response: *This question was addressed as part of question 4.*

3.6 Data Analysis:

The data collected from the case study interviews was condensed into summary table in an effort to identify common barriers and implementation trends among the firms. This “cutting and sorting” method groups the answers each of the questions and identifies any trends that might be present. The BIM creation processes identified in the interviews is represented graphically to show overlap and to serve as the basis for the proposed process presented by this research. A graphic for the BIM creation process for each firm was created to for use in creating the broader process proposed by this research. This comparison will illustrate the common methods used by the firms, indicative of methods that are working for BIM creation.

The ultimate goal of analyzing the case study interviews was to identify what has to go into the BIM creation process for it to be successful in creating models that are useful for in owners in managing their facilities. The firms that were interviewed have each created their own process and because there is not a standardized process for creating owner inspired models. These firms are fairly advanced BIM users and have been using their process on projects for several years. These processes are constant works-in-progress and have to be modified to fit the demands of owners and projects. The processes analyzed below are the processes that were in place at the time of the interview, and results of significant investment and commitment by the respective firms. The broader process this research presents is meant to be combine the strong aspects from these similar processes in an effort to give firms that do not have vast experience a starting point for creating models for their clients. Though this process is not exclusive to new BIM users, this is the group that is likely to gain the most benefit.

3.61 Interview Summary Table:

Interview Question	Case 1	Case 2	Case 3
1. Interviewee's Role at the Firm and in BIM Development	- BIM department director - Owner conferencing - Developed and coordinates BIM creation process - Creates BIM execution plan	- BIM department director - Owner conferencing - Coordinates BIM creation process - Creates BIM execution plan	- BIM department director - Manages a large portfolio with a BIM assisted FM program -Works with contractors to ensure models meet the needs of their FM program
2. BIM Development Process	- Models are created In-house by combing multiple design and engineering models - The BIM creation process is highly a collaborative process. * See Process Map	- Models are created in-house by combining multiple designs and engineering models. - The firm has in house structural and MEP engineers and detailers. * See Process Map	- The firm required the contractor to provide complete models for new construction that meet the provided BIM execution plan. - The firm is actively creating models for existing

			facilities in-house. * See Process Map
3. Model Utilization and Benefits	- Visualization (sales and design) for clients - Project sequencing - Trades coordination - Organize and share project documents and information - Clash Detection -Extract material quantities for estimating	- Central location for information / document storage, organization and sharing. - Trades coordination -Clash Detection - Visualization (sales and design) for clients	- Major component of FM program -Storage and organization of facility information and documents - Linked to Archibus FM software. - Space Management - Facility Maintenance Tasking - Renovation Planning
Interview Question	**Case 1**	**Case 2**	**Case 3**
4. Barriers to facility owners using BIM	- Owners do not understand what BIM is, its capabilities or its place in facility management. -Many owners that would like to use BIM as part of their facility management plan do	- The execution plan the firm has developed is very simple, and does not get down to the level that might be needed by the owner. - Many owners do not know what they need	- Some owners may not be educated properly in the capabilities of BIM. They know just enough

	not know what needs to be included in the model for it to be effective. - The creation of BIM execution plans is tedious. These are created by contractors and may not capture every task an owner may want to perform in FM.	in a model. - Current BIM creation process does not educate owner on the capabilities of BIM.	to be dangerous, not using BIM effectively. -Develop a long-term commitment and vision for using the software for efficient facility management. - Overcoming the sticker shock of the initial investment of resources and realizing the long-term benefits.
5. Owners' Involvement in model creation	- Owner involvement begins at project conceptualization. - Owners' needs to be expressed and incorporated early to avoid costly re-work.	- Owners are involved very early, the model serves as a tool in design and sales, reflecting owner input from the beginning. - Avoidance of retro-active model changes is important.	- As an owner, the firm is involved in the creation of a model from the beginning. - The firm provides the BIM execution plan to the contractor.

			-Constant involvement throughout construction to ensure model is accurate and up-to-date.
Interview Question	**Case 1**	**Case 2**	**Case 3**
6.Typical owner's requirements for a model	- There are no typical BIM requirements from owners. - The owner requirements depend on the facility complexity and the types of tasks in which BIM will be used. - Owner's uses are unique and the current processes developed by the firm to uncover these needs for model creation are lagging but constantly developing.	- Many of the firm's projects are similar (healthcare), so they have a good understanding is needed to manage a healthcare facility. - Many owners do not have defined model requirements and that is where the tedious creation of an execution plan comes in. - The owner requirements heavily depend on the types of FM tasks they will be using BIM to complete.	- Modeling requirements are different for each project. This depends on the facility type and intended uses now and in the future. - Model requirements are all included in the BIM execution plan that is provided to contractors. -The BIM execution plan details the LOD for

			each building component and the required non-graphic information.
7. Potential Model uses in facility management	-Benefits in FM similar to those seen by contractors. -Space Management -Organization of documents - Maintenance Tasking - Linked to FM software such as Archibus and COBie	- Model uses dependent on the quality, accuracy and LOD of the model - Non-graphic information is essential for many FM tasks -Future uses can include energy modeling and automated facility systems.	(Current Model Uses) -- Major component of FM program -Storage and organization of facility information and documents - Linked to Archibus FM software. - Space Management - Facility Maintenance Tasking - Renovation Planning
Interview Question	**Case 1**	**Case 2**	**Case 3**
8. Are owners using models for FM	- Some owners want the model just as a record but owners of more complex	- Owners are using it increasingly. - Currently, owners of	(Current Model Uses) - Major component

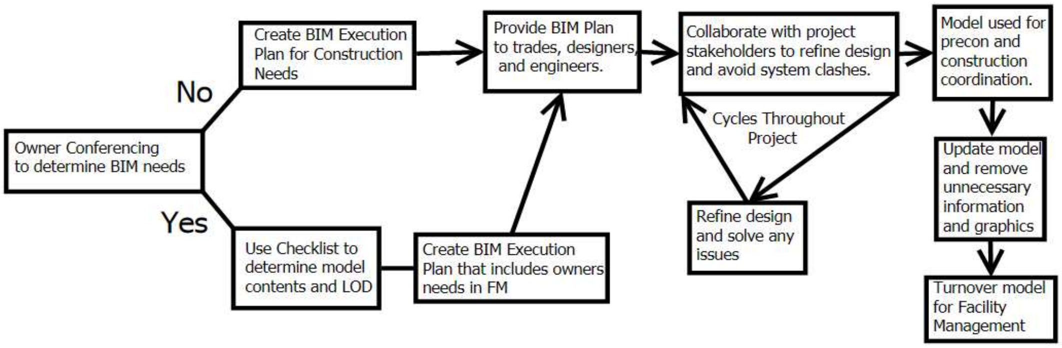
	facilities are using it more and more. - Many are using it in conjunction with a FM system (Archibus, COBie, etc.) -Information management is currently the biggest advantage to owners.	more complex facilities are using it the most. - Its often used with a FM program, but not always. - Owners can use the graphic dimension of BIM to find mechanical components, space management, and renovation planning.	of FM program -Storage and organization of facility information and documents - Linked to Archibus FM software. - Space Management - Facility Maintenance Tasking - Renovation Planning
9. Model turnover process	- The firm provides models to owners on a regular basis. - Advanced owners typically have an established process for model turnover - Less advanced owners may need education or technical assistance in integrating the technology. -Some owners need the contractor to assist in developing a complete FM program.	- Provides models to owners regularly. - The process is different for each owner, dependent upon BIM experience. - Some owners require education on how to navigate the model and extract information. -Firm is beginning to use their BIM expertise to develop FM plans for owners and long-term BIM maintenance.	- The owner has an established BIM department and need little assistance from the contractor. - The transfer of the model is typically only the transfer of the file and its ownership to the owner.

			-The owner noted that less experienced firms would need help in integrating the model into a FM plan. - A challenge of BIM is keeping it up-to-date and less advanced firms would likely need assistance here.
Interview Question	**Case 1**	**Case 2**	**Case 3**
10. Best ways to integrate BIM into FM	- A model is all about information. -Graphic development is important for organization, but comes second to the model information. -A well-developed model eliminates the need for owners to compile a large amount of facility information post-construction.	- A BIM is currently the best way to visually organize data, linking it to respective components makes it easy to find. -The development of the model determines its usefulness.	- The owner is currently seeing the most benefit from using BIM for space management, maintenance coordination, renovation planning, and as the main platform for information storage and

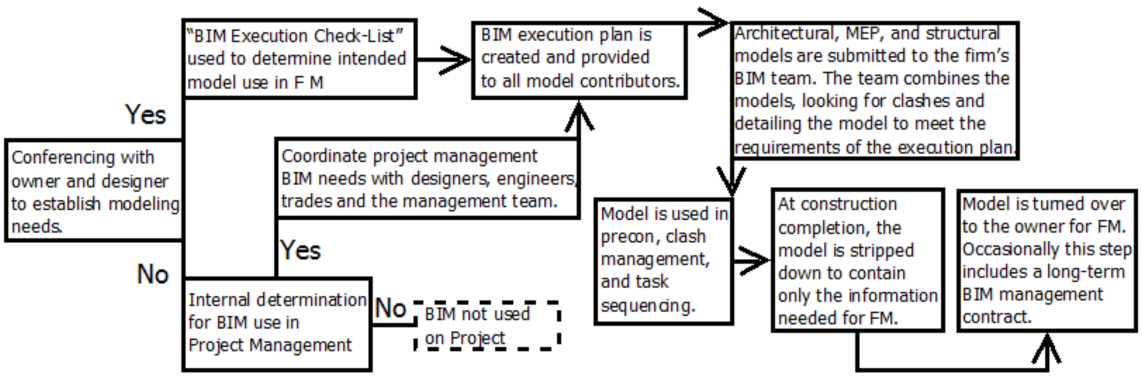
	- No matter how the model is integrated, it must be maintained or it will become obsolete.		organization.
11. Barriers of BIM compared to benefits	- The true return on investment of a model is difficult to measure, especially in the short term. - Technology always comes with a price tag and a learning curve, but the commitment to using and improving it makes the difference.	- The more developed a model is, the more it costs to create. However, more developed models offer more uses and consequently, more owner benefits. -The key to making BIM work is finding that balance between development, costs, and intended uses. -An investment in efficient facility management now, will lead to more useful, longer lasting buildings later.	- BIM use requires a long-term commitment and vision. - The sticker shock of initial investment in BIM integration is offset by the efficient management of a facility that pays off in the long-term.

3.7 Participants' BIM Development Processes

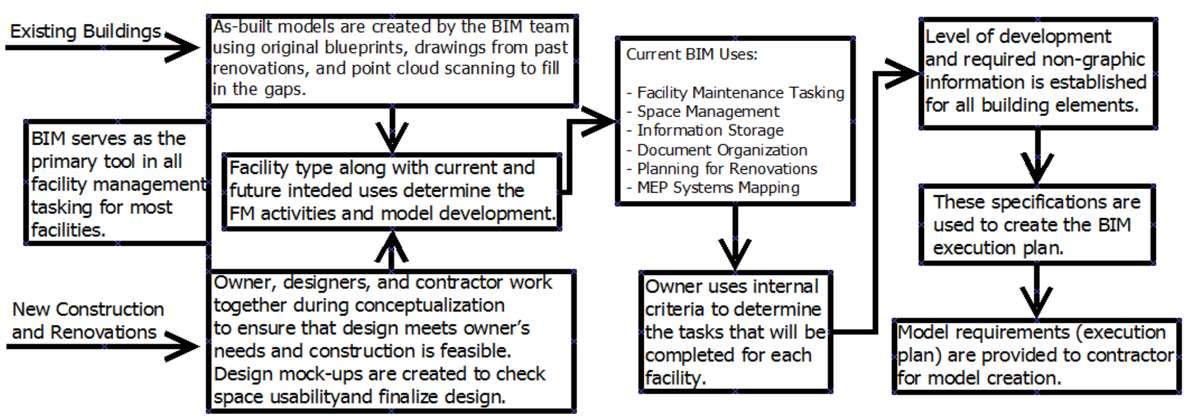
Case Study 1:



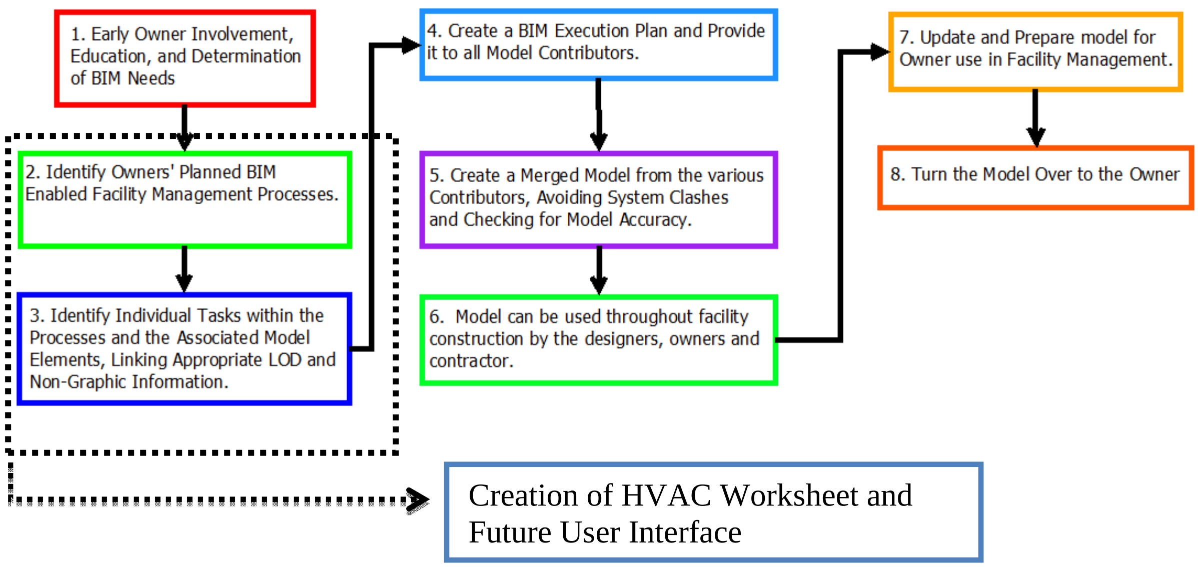
Case Study 2:



Case Study 3:



3.71 Proposed BIM Creation Process:



Step 1:

Educate the owner on the capabilities of BIM early in the design phase of construction, typically during conceptualization of design-build projects. When the owner has a grasp of the benefits and requirements of using BIM in a facility management plan, the contractor must determine the owners' desire for a facility model and BIM enabled facility management.

Step 1 Justification:

This first step in the proposed BIM creation process is evident in each of the case studies. In each case, the owner becomes involved early in the process of creating the model. Capturing owner requirements early all the designers and model contributors to include owners' requirements from the begging, reducing model rework. This early stage of owner involvement often requires the contractors or BIM professionals to educate owners on how the model can be applied in post-construction efforts.

Step 2:

Determine the facility management processes that the owner needs / wants to perform using BIM and the tasks that would most benefit the owner. The processes below represent the combination of the tasks currently being used by the large owner in case study three, and the processes presented by the *Pennsylvania State BIM Planning Guide for Facility Management*. These tasks are broad, and are comprised of many smaller sub-processes that make up the category

- Facility Maintenance Tasking
- Scheduling Activities
- Analyzing Facility Systems
- Asset Management
- Document Storage and Organization
- Space Management and Tracking
- Renovation Planning

Step 3:

Identify the individual tasks that should be performed to achieve each of the facility management processes. Then identify the appropriate LOD for the model elements that are part of the respective process (Structure, Floor Plan, HVAC, Equipment, etc.) and link the required Non-Graphic Information to the model that is needed to perform the process.

Steps 2 and 3 Justification:

If step one of the process indicates that the owner has a desire or need to include models in their facility management plan, the logical next step is to determine what the model needs to look like. The building components, level of graphic detail and non-graphic information included in the model determine what the facility management processes and tasks it can be used for. While a model is a graphic representation of the facility, the non-graphic information that is included in the model is the root of most management processes (Fuller, 2010).

In order to determine what a model should like when completed for facility management, it must be taken one building element at a time. The current processes used by all three case study firms is broader than they would like it to be, the process just has not proceeded to include all individual building components. The HVAC checklist or worksheet, that serves as part of this research, begins the process of developing a linkage between graphic representation, non-graphic data, and individual building components based on owners' intended model uses. This initial phase was to test the feasibility of arriving at a LOD and suggested non-graphic information for individual building components, streamlining the modeling process while simultaneously tailoring the model to fir owner needs.

Step 4:

Once the LOD's and Non-Graphic information have been identified for each of the facility elements, this information is presented in the form on a **BIM Execution Plan**. This document should be provided to all model contributors to maintain the quality and accuracy of the model.

Step 4 Justification:

In each of the cases, a BIM execution plan was created to provide specific directions to the parties contributing to and creating the model. The BIM execution plan is a comprehensive document that outlines in detail the requirements of the model per the owner. The execution plan is the standard to which the model is held and the reference for ensuring model completeness. Each of the cases study firms have developed a process for creating a BIM execution plan, but each of them have expressed that their process is not detailed enough to capture possible FM tasks and provide different LOD's for detailed building components. The future user interface will provide a medium for owner or contractor input that will produce a customized BIM execution plan that is backed by detailed information for all building components organized like the HVAC worksheet introduced by this research. The detailed development of tasking linked to LOD's and non-graphic information is an effort that the second case study firm is interested in pursuing internally.

Step 5:

Each of the model contributors such as designers, engineers, trades specialist, and in-house designers should adhere to the specifications of the Execution Plan. The various model parts created by the contributors should be combined to create the comprehensive model. The merging of models will require a fairly collaborative approach by all involved in order to effectively avoid system clashes and to maintain the accuracy of model information. The information included in the model should include any additional information that may be needed by the contractor for construction purposes.

Step 5 Justification:

While only the first case study firm had a formalized process for encouraging collaboration among model contributors, each of the firms participate in collaborative BIM creation. The first and second case studies each collaborate with model contributors throughout the modeling process to pro-actively avoid clashes and model inaccuracies. The third case is an owner that creates their execution plan through collaboration with facility users. This firm has the most developed execution plan that provides more detail to the model contributors. This step of model creation intuitively comes just after the execution plan. The collaboration aspect is conducted at various levels by each of the firms.

Step 6:

The model created through this collaborative process can be used by the contractor, owner and designer throughout the construction process to monitor quality, work progress and to make pro-active facility changes.

Step 6 Justification:

Each of the cases use the model for construction related needs after it is created. This is the most elemental reason that contractors began using models and the place that owners beginning realizing the benefits afforded by model use (Becerik-Gerber, Jazizadeh, Calis, 2012. The models created for construction are not always intended to be used by owners for facility management, leading to step seven.

Step 7:

At the completion of construction the model needs to be prepared for the owner's use in facility management. This preparation includes ensuring that all facility changes have been made to the model, construction related information not requested by the Execution Plan be removed, and that all final construction documents, manuals, warranties and schedules be attached to the model in accordance with manufacturer instructions and as called for by the Execution Plan.

Step 7 Justification:

Models are used in design, preconstruction and through the physical construction of facilities. The model information required for facility construction is not always the same information needed for facility management. After construction completion the model must be updated to ensure that unneeded information is removed and that required information is up-to-date and accurate. This often requires revisiting the execution plan and accounting for project changes, creating essentially an "As-Built Model".

Step 8:

When the model is updated to be comprehensive and accurate, it is ready for the owner to use as part of their facility management program. The integration of the model into the facility management program is going to be dependent on the owner. Owner's that have personnel and experience may not need any help to make effectively integrate model. Owners with less experience and man-power may rely heavily on the contractor for integrating the model. If contractors develop appropriate in-house knowledge and personnel, there is potential for long-term contracts that include FM program creation and model maintenance.

Step 8 Justification:

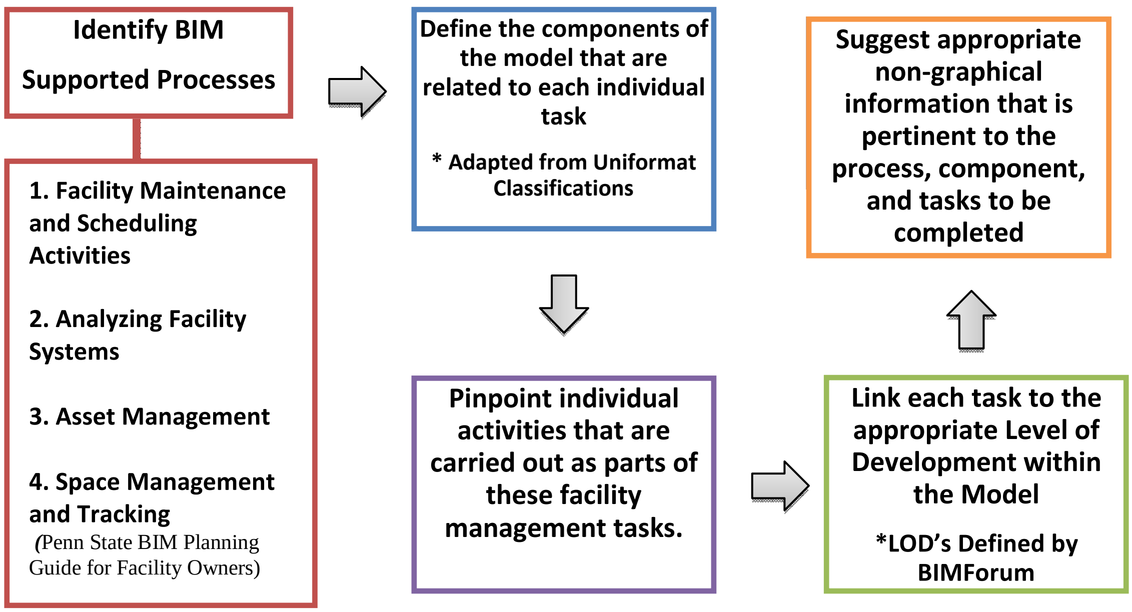
After the model is created, used for construction and updated to reflect owner needs, the model must be turned-over to the owner. The turnover process varies depending the needs of the owner and presents an opportunity for contractors to develop expertise in creating and maintaining BIM enabled facility management programs. The first two firms are both beginning to explore this avenue.

3.8 Facility Management Process – Tasking

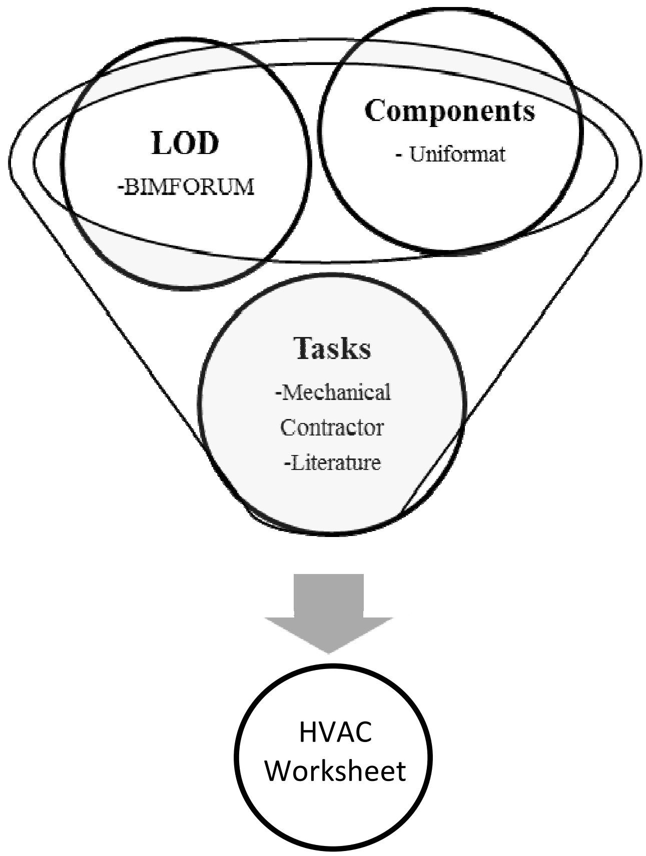
Facility owners each have unique processes as part of their facility management programs. These processes often include space management, physical maintenance, document control and much more. The process above is meant help in the creation of models that can be used by owners as part of a facility management plan. The models have to be developed in such a way that the information they contain is useful and easily accessible. This means that the information that is linked to the respective graphic components in model must be correct and complete. This is a common obstacle faced by the case study firms to various degrees. The firms have created checklist that guide in the creation of the BIM execution plan and ultimately the model, but these lists are incomplete, fairly generic and are tedious to complete.

The HVAC worksheet presented in chapter four is the pilot for a series of worksheets that will be created in future research. The worksheet is designed in a question based format that intends to link model graphic development and non-graphic information to the tasks that a facility owner may need to complete as part of a facility management plan. The worksheets are created to make sure that the information contained in the model is complete. The worksheets will be designed for each of the building components as defined by Uniformat. The worksheets will accomplish two objectives. First, they will provide a paper-based tool that can be evaluated for completeness and project feasibility. Once evaluated, the worksheets can be transformed into digital format that will run as a software application, producing BIM execution plans from simple question-answer user input. The HVAC worksheet for Facility Maintenance is the first in the series or worksheets that sets the stage for the future research phases. The worksheet was created by using the uniformat building component break-down, information from numerous HVAC maintenance schedules and input from a commercial HVAC contractor. The finer details of the HVAC worksheet creation are expressed in chapter four.

Chapter 4: Development of HVAC Worksheet



The HVAC worksheet compiles current knowledge including BIM level of Developments (BIMForum) and Building Element Classifications (Uniformat) with maintenance tasks from various sources including HVAC trade associations, a mechanical contractor and unit maintenance schedules to create a worksheet for the development of a BIM that could be used to assist in physical facility management and maintenance. This worksheet is a small part of the big picture, which is the creation of a digital tool for use by novice contractors to create models for owners. This worksheet has been developed to test the process for effectiveness before future worksheets are developed to serve as the organization and background operations of the digital interface. In an effort to address the research problem as identified in the literature and reinforced by the research interviews, a worksheet was developed for the chosen facility service system, HVAC. The purpose of this worksheet is to list activities commonly performed as part of an HVAC maintenance program that are linked to the appropriate LOD and non-graphic information.



The first step in the creation of the HVAC facility maintenance worksheet was to define the levels of development that would be used. The levels of development used by all of the interviewed firms were established by the BIMFORUM in collaboration with the American Institute of Architects. The most recent specification release (2013) was used. A brief description of the specifications can be found below. A detailed explanation can be found in appendix 2.

BIMFORUM Level of Development Specifications 2013

Level of Development	**BIMFORUM Descriptions**
100	Element is graphically represented with a symbol. No non-graphic information is attached.
200	Element is represented as a generic shape with approximate location. Non-graphic information may be attached.
300	Element is represented as a specific item with accurate location. Non-graphic information may be attached.
350	Element is represented as a specific item with accurate location. Element relationships to other building systems may be shown. Non-graphic information may be attached.
400	Element is represented as a specific item with accurate location. Element will include fabrication details. Non-graphic information may be attached.
500	Element is a realistic, field verified representation. Non-graphic information may be attached.

In keeping with the organization of the LOD Specifications, the HVAC worksheet was organized into categories reflective of Uniformat building element organization. These categories include the major components of a commercial HVAC system. Defining the included components was done with collaboration from the manager of the commercial maintenance department from Waldrop Mechanical. The maintenance manager provided an extensive document that outlines regular maintenance and repair tasking for HVAC systems and components. This document is updated annually to reflect changes in HVAC components and manufacturers' suggested maintenance scheduling. Many of the tasks in the worksheet were adapted from this document that contained a series of checklists. These tasks, along with tasks adapted from the Air Conditioned Association of America (ACCA) and the South Carolina Association of Heating and Air

Conditioning Contractors (SCAHACC), were used in the creation of the tasking laid out in the HVAC worksheet.

Each of the tasks that are represented in the worksheet is tied to a specific component of the HVAC system. The components organization is based off of Uniformat, but is condensed to reduce the size of the worksheet. The tasks include preventive maintenance, regular repair items, and tasks that could be part of future owner needs. The varied nature of the tasking requires numerous types of information and could benefit from varied levels of graphic representation. The tasks were linked to the appropriate level of detail depending on the detail level of the components undergoing maintenance and the nature of the tasks. General maintenance tasking that did not focus on a particular component is represented at a lower level of detail while a task involving a specific component is at a higher level of detail. The tasks that were represented at higher levels of detail in the worksheet are tasks that require locating specific components or often locating access points to perform specific maintenance or repair activities.

Graphic representation of building elements at the appropriate level of detail does not provide the owner with all the information needed to perform most tasks (East, Brodt, 2008). Though the model is a spatial representation of a building, it has the capability of storing large amounts of non-graphic information. Non-graphic information is any document that can be attached to a model element. The nature of the non-graphic information depends heavily upon the element and the type of task to be completed. A bank of potential non-graphic information was created by combing through the mechanical contractor's maintenance worksheets, adapted from the CAAG, conversations with the manager of the commercial maintenance department, interviews, and the Penn State “BIM Planning Guide for Facility Owners”. The last column of the HVAC worksheet identifies potential non-graphic information that would be helpful in executing the task. The bank of non-graphic information is listed below.

Non Graphic Information

Non-Graphic Information	Sources Interviews	Mechanical Contractor	Penn State BIM Guide	ACCA
Design Specifications	X	X		
Construction Documents	X		X	
As-Built Drawings	X		X	
Building Permits	X			
Fabrication Details	X	X		
Isometric Drawings	X			
Material Quantities		X		
Material Specifications	X			
Operation Test Reports		X		
Inspection Records		X		
Energy Usage and Cost Records			X	
Safety Information		X		
Manufacturers’ Operation Instructions		X	X	X
Manufacturer Warranty Information			X	X
Original Vendor Information			X	
Preventative Maintenance Schedules	X			X
Component Replacement Schedules	X			
Electrical Diagrams	X	X		
Inventory of Replacement Parts	X			
Component Identification Numbers			X	

Chapter 5: Verification Strategy and Future Research

In an effort to ensure the soundness of the information extracted from the interviews and its use in the creation of the resulting framework and ultimately the facility maintenance worksheet, the research has utilized the verification strategy of "member-checking" (Creswell, 2013). This verification strategy includes submitting the framework to the interviewees and eliciting feedback through a follow-up interview. The follow-up interview invited the respondents to review the worksheet developed by this research to check that the process was both viable and feasibly for implementation, the tasking was accurate and complete and that the non-graphic information suggestions were both accurate and comprehensive. The feedback was ultimately used to make revisions to the original worksheet to ensure that it is meeting the needs of contractors but with owners' needs in mind.

The final stage of the research was *Objective #3: Verify tasking information through industry feedback.* To achieve the last research objective, the worksheet was submitted back to two of the originally-interviewed firms for review. After the firms had a chance to review the worksheet, they participated in a follow-up interview to gain their perspective on the information that is contained in the worksheet. This verification process was conducted to ensure that the information contained in the worksheet was correct; that the tasks represented the most common maintenance tasking; that the tasks were at the appropriate level of detail; and that the suggested non-graphic information was correct, complete and would be useful. The verification process ensured that the worksheet was correct and practical for application.

5.1 Verification Interview 1: Owner

The first verification interview took place with the BIM Director for the advanced owner. The director reviewed the worksheet and indicated that the worksheet seemed to capture most maintenance activities that would occur on their HVAC system. She suggested that some of the task be moved to a lower level of development because many times the attached non-graphic information would provide enough information to perform the task. She suggested that often they do not have models that are above a LOD 300 because of the difficulty of storing and maintaining a model that was so detailed. She agreed that the worksheet included all the information they would need to perform maintenance tasks on the HVAC system. The director felt that the suggested non-graphical information was complete. She felt that the list of information was - too detailed for most applications and that some items could be removed. She noted that the worksheet would be a valuable tool for an owner or contractor who had little experience in developing information for a model.

5.2 Verification Interview 2: Contractor

The second verification interview took place with the BIM director and MEP Designer of the medium-sized construction firm. As with the first validation interview, the worksheet was shared with the firm for review and was followed with an interview. While the owner felt that most tasks could be done at a level 300 or below, the representatives from the construction firms suggested that their clients often prefer to be at a level 350 for the additional detail and to show element interaction with other systems. They said that often the model is developed beyond this for use by the contractor and fabricators, but the model is often stripped down to contain only the information the owner needs as to not make it too tedious for the owner to maintain. This process is often hit or miss and having a tool that allows them to be more accurate with what is left in the model would be helpful. They felt that the non-graphic information was too detailed and could stand to be trimmed back. However, they were very interested in the process and framework that had been created for the HVAC system. They said that as a company, they were in the process of developing a similar process by creating extensive checklists that help them to create models that reflected their clients' needs. They are very interested in seeing the completed research and the process used to create the worksheet. At the end of the interview, they mentioned their excitement and interest in participating in further research on the subject, seeing it as having great value for their firm.

5.3 Finalizing the Worksheet:

After the verification process, the worksheet was changed to reflect the changes indicated by the reviewers. Both of the respondents suggested that less non-graphic information be included and, for this reason, some of the suggested documents were removed to reflect a leaner worksheet. The tasks were shifted slightly to reflect the LOD's the reviewers thought would be most useful and manageable. The owner is limited to the applications of BIM in their own facilities while the contractor deals with a larger variety of owners. In an effort to make the worksheet more applicable to a larger group of owners, the tasks were moved to reflect the feedback of the contractor more so than the advanced owner.

Both the contractor and owners stated that often level 400 is not needed except for fabrication and would have limited application to facility maintenance tasks. Though this heavily weighed on the decision to keep or remove level 400 tasking and development, the ultimate decision was to keep the level but to modify some of the tasks. This judgment was based on the potential for future energy monitoring applications. While BIM enabled energy monitoring is still in its early stages, it is likely that this process will require the higher level BIM development (Costa, Keane, Torrens, Corry, 2013). Level 400 developments were left in the worksheet but only attached to energy monitoring tasking. This will allow the worksheet to be viable into the future as energy monitoring technology progresses and provides the owner with the option of having the model developed at this level.

5.4 Future of the Worksheet:

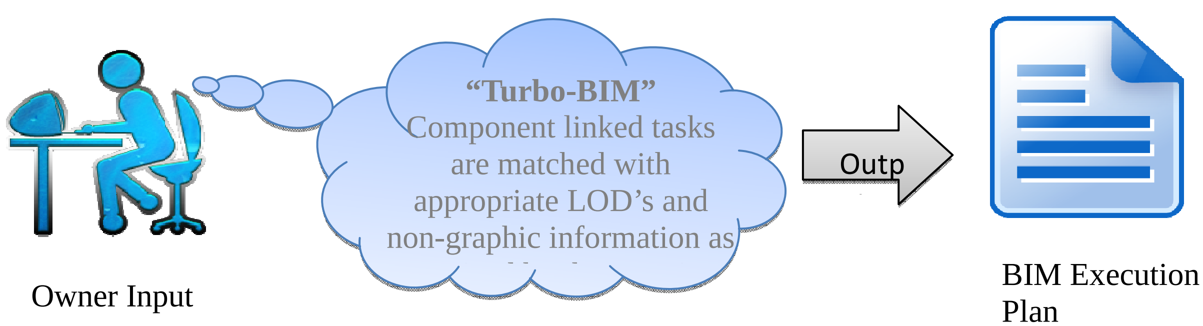
The worksheet was developed to organize the tasks and non-graphic information with the respective level of development. The instructions for using the worksheet are fairly simple, asking that the user check the corresponding block beside each task that they plan to perform. The checked block corresponds to a level of development and a list of non-graphic information that should be included in the model.

The future of the framework is to develop a worksheet for every building element group represented in Uniformat. The worksheet for each group will be similar to that developed for HVAC and contain tasks specific to that group. Initial organization of this information will be worksheets just like what has been done for HVAC. These worksheets are not the final goal for the framework. If future research is able to develop a worksheet for each of the building groups, this organization of validated information will be transformed into a digital interface that eliminates the need to fill out dozens of worksheets. The interface will allow users to select the tasks they plan to perform and the background of the interface will perform the matching of tasks with the appropriate level of detail and non-graphic information. After a user has answered the questions in the interface, the system will produce an output that reflects a summary of tasks, the appropriate LOD for each group of elements, and the information that needs to linked to the model.

5.5 Future Research: Digital Interface:

The worksheets as developed by this and future research are created to organize and evaluate maintenance tasks, and then link these tasks to the appropriate level of detail and data needs. Once this information has been compiled and verified for all building components, the next step and ultimate goal of this research is to create a user interface. The development of a digital interface will resemble a survey that provides a list of questions (tasks) and requires the owner or contractor to provide a simple yes or no answer. This interface could be executed as a website or even a software package. The creation of the interface will involve user participation and field testing to arrive at the most accurate and user friendly version possible.

The user interface will require in-depth testing and development of worksheets or checklist for each group building elements. The information in these checklists must be verified with industry professionals to check for accuracy and completeness. Before the digital interface is created in the checklists will need to be evaluated, ideally on real projects. This evaluation will test the true value of this information organization and determine if progression to digital interface development is warranted. The development of a user interface will require extensive time commitments, the securing of funding, and the efforts of others that have experience in creating software or applications.



Chapter 6: Conclusions

As modeling technology becomes more advanced and accessible, more and more contractors and owners will be able to reap the benefits of adoption. While there are several complex barriers that are preventing widespread adoption by owners, creating models that represent their needs is a step in the right direction. The capabilities of BIM in facility management are numerous, but the model is only as strong as the information it contains. It seems that all too often contractors and owners create a BIM for use that does not meet the needs of the owners or is too detailed to practically maintain. If the information can be kept at a minimum but still meet the needs of owners and contractors, the amount of work will be reduced and the effort of creating a model will not be wasted.

This research has created conceptual method for creating models that meet owners' needs. Many larger contracting firms and owners are developing their own process for creating models. However, there are still many owners and contractors who do not use BIM. This framework is meant to help those who do not use the technology but have a desire or need to utilize its benefits. This worksheet is not the complete answer to the presented problem but it contributes in helping smaller contractors gain business opportunities with larger owners and helps small owners begin using BIM to better manage their facilities.

6.0 Research Objectives

Objective #1: Identify successful implementation practices of BIM in facility management.

The use of models in facility management is dependent on several factors. The use of models in facility management programs depends on the knowledge and commitment of owners. There are various uses of models to FM programs, but the model must be developed with these uses in mind. Contractors are encountering more and more owners who what to use BIM in FM but are facing the challenge of creating models that will be useful and maintainable in the future. The firms that participating the case studies have each developed their own process for creating models, these models meet both the needs of the contractor during construction the owners post-construction. The model creation processes are unique to each firm but are encountering the obstacle of identifying the appropriate information and educating owners on the uses of BIM.

Objective #2: Develop a conceptual process for owner-facilitated BIM creation and contractor-to-owner model turnover.

The research proposes a general process that contractors can take and develop to meet the needs of their firm and clients. The general process is a combination of the processes used by the advanced firms that were interviewed. This best practice process is closely tied to processes that have been sued by these advanced firms on multiple complex projects. The process is generic in nature but is logical and easily replicated. The identification of tasks associated with each of the identified process is a cumbersome task that this research has only begun to overcome. This research has presented the pilot to task identification in the form of the HVAC worksheet, and has set the stage for future research that will create tasking sheets for the remainder of the building processes and eventually create the digital user interface for BIM execution plan creation.

6.1 Research Limitations

Despite efforts to ensure the completeness of the research, inevitably there were limitations to the research. The following sections describe the limitations that were faced and how they were addressed.

6.11 Location and Quantity of Interviews

The research was limited to the Southeastern United States. The firms that were interviewed were all located within a few hours' drive of Clemson, SC. One of the firms was located in South Carolina, one was in Georgia, and the last two were in North Carolina. The limitation of location was imposed by the ability to travel which was controlled by research funding and time. Due to the limitation of location, another limitation was imposed upon the research and the quantity of interviews that could be conducted. Many of the construction firms in the designated area do not have advanced BIM processes and were not as seen as valuable to the research.

It was important for the interviews to be in-person for several reasons. The processes used to create models involved documents that could not be distributed outside of the firm, but were shown during the interviews. The in-person interviews allowed for the viewing of not only these documents but the models that resulted from them, again these files could not provide outside these organizations. While virtual formats such as Skype or even phone interviews could have allowed us to reach more firms in a greater geographic region, the in-person interviews allowed for more control over detailed questions and made it easier for respondents to provide and explain detailed responses, often with examples of their work.

To combat the consequences of this limitation, the efforts of the research were concentrated on firms that have extensive BIM knowledge and advanced processes, producing the most value for the research. Future research should make efforts to secure funding and designate enough time to pursue interviewing more advanced contractors and owners. These firms should be more geographically dispersed across the United States; this effort will ensure that the research is applicable to a more contractors and owners.

6.12 Limited Development of Worksheet

The worksheet was only developed for HVAC components of a building. The development of the one service system was elected because of the extent of the information that is required to develop a single service. HVAC was selected because it allowed the development of tasks at many LOD's, and there was a mechanical contractor interested in the research and willing to share their maintenance tasking. The development of a single worksheet allowed for the ability to test the process for feasibility before exerting the effort required to develop a worksheet for each building element, which is a part of future research.

Future research will require a worksheet to be developed and tested for each of the other element groups, as defined by Uniformat. The development of these worksheets will require input from industry professionals with extensive knowledge and experience with the element group. It would be most beneficial if these professionals have some experience with using or creating models.

6.13 Verification

Every effort was made to ensure the accuracy of the information used to create the HVAC worksheet and proposed process. The information used came from trusted sources and was submitted to the interviewees to ensure accuracy of information, completeness, and perceived feasibility of application. This member-checking verification was limited to two of the original interviewees, due to the availability of the other two interviewees. In an effort to combat this limitation, the validation also included the MEP BIM designer from the medium sized construction firm. The designer specializes in the modeling of MEP components and lent insight into the development of the worksheet.

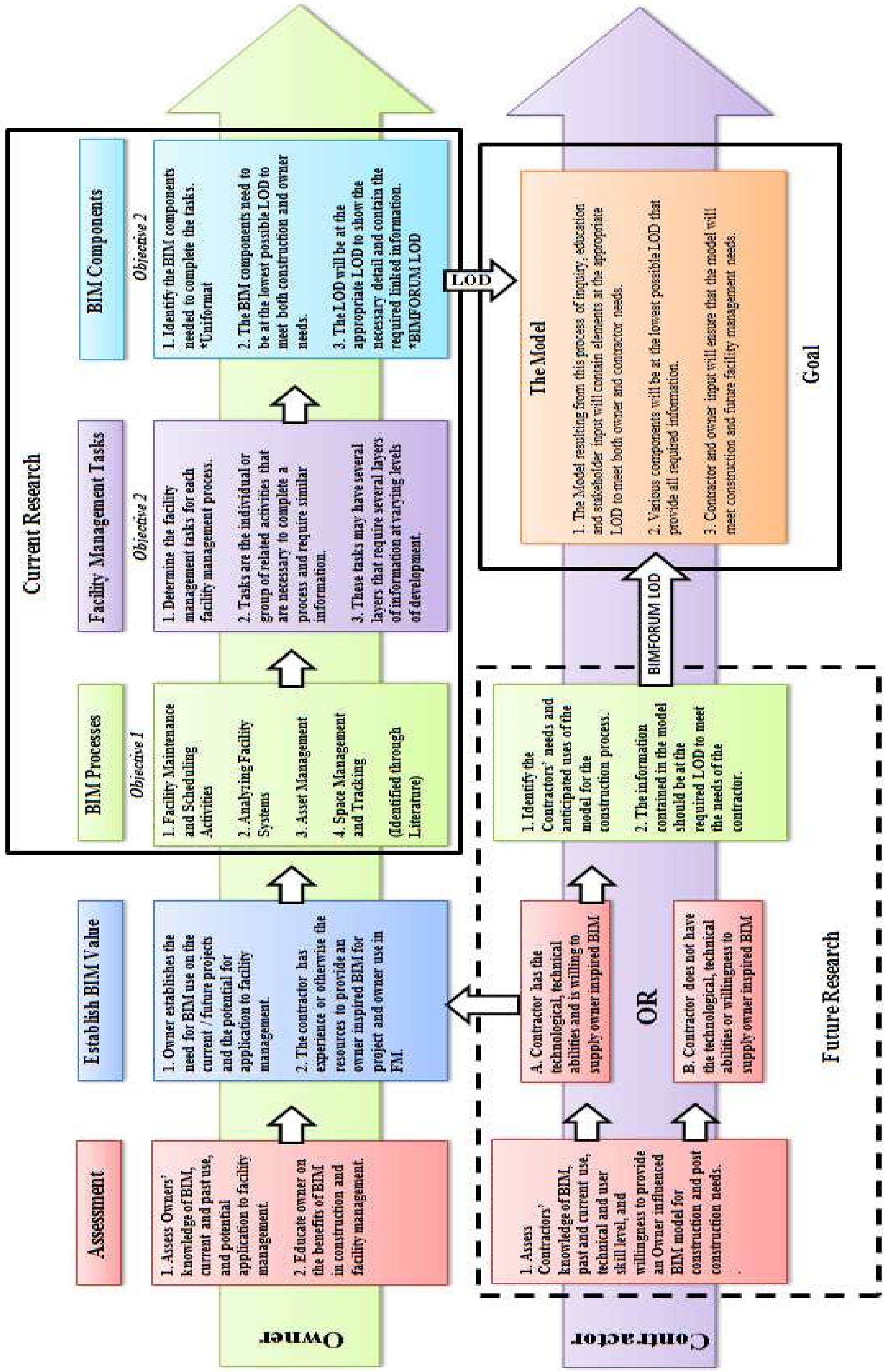
Future of worksheet verification will be to gain the perception and buy-in from a larger number of industry professionals. Beyond information verification, the next step is to apply the worksheet to actual projects and evaluate its effectiveness in practice. This can be done with less advanced owners and contractors for whom this worksheet was developed

6.2 Contributions

BIM's journey to becoming practical for use is still very much underway. This research has taken current bodies of accepted knowledge and combined them with practical applications in a way to be useful to less advanced contractors and owner. The research being done on BIM has been about establishing standards for development, organization, and implementation, but little has been done to advance practical application of BIM's capabilities. Many uses of BIM look great on paper but just are not currently practical. This research serves as a pilot to a larger body of future research that could turn into a substantial tool for contractors and owners, helping make the transition to using BIM less cumbersome and more practical.

APPENDICES

Appendix 1: Concept Map



Appendix 2: BIMFORUM Level of Development Specifications

Fundamental LOD Definitions

LOD 100: The Model Element may be graphically represented in the Model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements.

LOD 200: The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.

LOD 300: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.

LOD 350: The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.

LOD 400: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.

LOD 500: The Model Element is a field verified representation in terms of size, shape, location, quantity, and

* Taken from the 2013 BIMFORUM Level of Development Specification

Appendix 3: HVAC Maintenance Worksheet

Instructions for Completion

Description

The following worksheet is designed to help owners, contractors and BIM designers to arrive at the appropriate Level of Development for a Building Information Model of the facility HVAC system. The worksheet is a compilation of common facility maintenance task associated with maintaining most types of heating and cooling systems. To accommodate the various types of HVAC systems the tasks are slightly general but applicable to various types of systems and facilities.

1. The first column labeled “Component” describes the group of HVAC components that each task to the right is linked to.

2. The second column lists a series of common maintenance and planning tasks in maintaining the respective HVAC elements. There is a series of six columns directly right of the tasks with an unshaded block that corresponds to the LOD needed to perform the task.

3. The last column contains a list of suggested non-graphic information that could be linked to the model to assist in performing the particular task.

Instructions

Together, the owner and contractor or BIM designer, should go through this worksheet from top to bottom from left to right. For each facility management task, the owner should determine if the tasks is part of their facility management programs or plans. If a task is to be performed by the owner, check or otherwise mark the blank box that corresponds to appropriate LOD. The highest LOD in each section of elements determines the level to which that group of elements should be modeled. However, it may be useful to work through all tasks to determine what non-graphic information should be linked to the model.

Non-Graphic Information

- Design Specifications
- Construction Documents
- As-Built Drawings
- Building Permits
- Fabrication Details
- Isometric Drawings
- Material Quantities
- Material Specifications
- Operation Test Reports
- Inspection Reports
- Energy Usage and Cost Records
- Safety Information
- Manufacturers' Operation Instructions
- Manufacturer warranty Information
- Original Vendor Information
- Preventative Maintenance Schedules
- Electrical Diagrams
- Inventory of Replacement Parts
- Component Identification Number

Facility HVAC System Maintenance

Level of Development Worksheet

	Planned Facility Management Tasks	400	350	300	200	100	NO BIM	Suggested Non-Graphic Information
Energy Supply and Piping	Pair the HVAC fuel components to energy monitoring systems to evaluate fuel use efficiency.							-Material Specifications -Operation Test Reports -Energy Usage and Cost Records -Component Identification Numbers -Electrical Diagrams
	Access operation and fabrication details for evaluating system changes and major repair.							-Fabrication Details -Isometric Drawings -Component Identification Numbers -Safety Information -Electrical Diagrams -Inventory of Replacement Parts -Material Quantities -Material Specifications
	Training maintenance staff on the layout and functions of the HVAC fuel systems.							-Isometric Drawings -Safety Information -Component Identification Numbers -Manufacturers' Operation Instructions
	Demonstrate compliance of fuel system in meeting safety and building code requirements.							-Building Permits -Operation Test Reports -Inspection Reports -Manufacturers' Operation Instructions -Safety Information -Component Identification Numbers
	Conduct preventive or repair maintenance on fuel piping, fittings, valves, insulation and supports.							-Inspection Reports -Inventory of Replacement Parts -Component Identification Numbers -Safety Information -Preventative Maintenance Schedules -Material Quantities

								-Material Specifications -Operation Test Reports
	Map fuel system exact locations when planning for facility renovations.							-As-Built Drawings -Isometric Drawings -Safety Information -Electrical Diagrams -Component Identification Numbers
	Locate and repair pumps or valves in case of failure. Identify effected connected components, take appropriate safety precautions and identify correct replacement parts.							-Material Quantities -Material Specifications -Fabrication Details -Safety Information -Electrical Diagrams -Component Identification Numbers -Manufacturers' Operation Instructions -Manufacturer warranty Information -Original Vendor -Inventory of Replacement Parts
	Conduct scheduled inspections on fuel piping, fittings, valves, insulation, pumps and supports.							-Component Identification Numbers -Preventative Maintenance Schedules -Operation Test Reports
	Locate oil filters for repair, replacement or inspection.							-Safety Information -Manufacturers' Operation Instructions -Inventory of Replacement Parts -Component Identification Numbers
	Map fuel systems when planning for demolition of facility components or structure.							-Safety Information -As-Built Drawings -Electrical Diagrams -Component Identification Numbers
	Only need non-graphic information linked to the component in the model. No need for detailed graphics.							-Safety Information -Manufacturers' Operation Instructions -Manufacturer warranty Information -Original Vendor Information -Preventative Maintenance Schedules -Component

								Identification Numbers -Isometric Drawings -Material Specifications
	Reference the fuel systems basic layout and flow directions. The system will be represented only by symbols to show approximate location.							**None**
	*I have no planned activities related to the fuel systems.							**None**
	Management Tasks	400	350	300	200	100	NB	Non-Graphic Information
Heating Systems	Pair the heat generating units to energy monitoring systems to evaluate energy efficiency.							-Material Specifications -Operation Test Reports -Energy Usage and Cost Records -Component Identification Numbers -Electrical Diagrams
	Access operation and fabrication details for evaluating system changes and major repair.							-Fabrication Details -Isometric Drawings -Component Identification Numbers -Safety Information -Electrical Diagrams -Inventory of Replacement Parts -Material Quantities -Material

								Specifications
	Demonstrate compliance of heating system in meeting safety and building code requirements.							-Building Permits -Operation Test Reports -Inspection Reports -Manufacturers' Operation Instructions -Safety Information -Component Identification Numbers
	Train maintenance or operating personnel on the repair and operation of heat generating systems and components.							-Isometric Drawings -Safety Information -Component Identification Numbers -Manufacturers' Operation Instructions
	Maintain system supports and vibration isolation points.							-Component Identification Numbers -Manufacturers' Operation Instructions -Fabrication Details -Isometric Drawings
	Troubleshoot faulty heating systems and connected services (air, water, oil, electrical) and systems.							-Isometric Drawings -Safety Information -Operation Test Reports -Material Specifications -Manufacturers' Operation Instructions -Electrical Diagrams -Component Identification Numbers
	Perform scheduled cleaning and inspection of heating system. (heating coils, boilers, motors, water and air inlets, valves, piping, electrical connections, emergency shut offs, and tanks)							-Component Identification Numbers -Preventative Maintenance Schedules -Operation Test Reports
	Map heating units' exact locations when planning for facility renovations.							-As-Built Drawings -Isometric Drawings -Safety Information -Electrical Diagrams -Component Identification Numbers
	Locate decentralized heating units throughout facility and perform scheduled maintenance or repair.							-Preventative Maintenance Schedules -Electrical Diagrams

								-Inventory of Replacement Parts -Component Identification Numbers -As-Built Drawings -Manufacturers' Operation Instructions
	Assess unit clearance requirements mandated by building codes officials.							-Component Identification Numbers -Manufacturers' Operation Instructions -Safety Information
	Locate and repair components in case of failure. Identify effected connected components, take appropriate safety precautions and identify correct replacement parts.							-Material Quantities -Material Specifications -Fabrication Details -Safety Information -Electrical Diagrams -Component Identification Numbers -Manufacturers' Operation Instructions -Manufacturer warranty Information -Original Vendor Information -Inventory of Replacement Parts
	Perform scheduled maintenance to wear components (belts, filters, bearings, and hoses).							-Inspection Reports -Inventory of Replacement Parts -Component Identification Numbers -Safety Information -Preventative Maintenance Schedules -Material Quantities -Material Specifications -Operation Test Reports
	Only need non-graphic information linked to the component in the model. No need for detailed graphics.							-Safety Information -Manufacturers' Operation Instructions -Manufacturer warranty Information -Original Vendor Information -Preventative Maintenance Schedules -Component Identification Numbers -Isometric Drawings -Material Specifications

	Map approximate locations of heating units when planning for demolition of facility components or structure.							-Safety Information -As-Built Drawings -Electrical Diagrams -Component Identification Numbers
	Have heat generating systems generically represented only symbolically to show basic relationships to other systems.							**None**
	*I have no maintenance activities related to the heating systems.							**None**
	Management Tasks	400	350	300	200	100	NB	Non-Graphic Information
Cool Generating Systems	Pair the cooling units to energy monitoring systems to evaluate energy efficiency.							-Material Specifications -Operation Test Reports -Energy Usage and Cost Records -Component Identification Numbers -Electrical Diagrams
	Access operation and fabrication details for evaluating system changes and major repair.							-Fabrication Details -Isometric Drawings -Component Identification Numbers -Safety Information -Electrical Diagrams -Inventory of Replacement Parts -Material Quantities -Material Specifications
	Demonstrate compliance of cooling system in meeting safety and building code requirements.							-Building Permits -Operation Test Reports -Inspection Reports -Manufacturers' Operation Instructions -Safety Information -Component Identification Numbers
	Train maintenance or operating personnel on the repair and operation of cooling systems and components.							-Isometric Drawings -Safety Information -Component Identification Numbers -Manufacturers' Operation Instructions
	Inspect electrical connections and emergency shutoffs							-Isometric Drawings -Electrical Diagrams -Safety Information
	Perform scheduled cleaning and							-Component

	inspection of cooling system. (compressors, blower motors, water and air inlets, valves, piping, electrical connections, emergency shut offs, and condensers)							Identification Numbers -Preventative Maintenance Schedules -Operation Test Reports
	Locate and repair components in case of failure. Identify effected connected components, take appropriate safety precautions and identify correct replacement parts.							-Material Quantities -Material Specifications -Fabrication Details -Safety Information -Electrical Diagrams -Component Identification Numbers -Manufacturers' Operation Instructions -Manufacturer warranty Information -Original Vendor Information -Inventory of Replacement parts
	Perform scheduled maintenance to wear components (belts, filters, bearings, and hoses).							-Inspection Reports -Inventory of Replacement Parts -Component Identification Numbers -Safety Information -Preventative Maintenance Schedules -Material Quantities -Material Specifications -Operation Test Reports
	Perform scheduled maintenance on unit compressors and condensers							-Inspection Reports -Inventory of Replacement Parts -Component Identification Numbers -Safety Information -Preventative Maintenance Schedules -Material Quantities -Material Specifications -Operation Test Reports
	Perform scheduled cleaning and inspection of evaporative cooling system. (cooling towers)							-Component Identification Numbers -Preventative Maintenance Schedules -Operation Test Reports

	Locate and check coolant agent levels and performance.							-Preventative Maintenance Schedules -Inventory of Replacement Parts -Component Identification Numbers -Safety Information -Manufacturers' Operation Instructions
	Map cooling system when planning for renovations.							-As-Built Drawings -Isometric Drawings -Safety Information -Electrical Diagrams -Component Identification Numbers
	Identify approximate location of units, estimated measurements and access clearance.							-Component Identification Numbers -As-Built Drawings -Manufacturers' Operation Instructions -Safety Information
	Map approximate locations of cooling units when planning for demolition of facility components or structure.							-Safety Information -As-Built Drawings -Electrical Diagrams -Component Identification Numbers
	Only need basic non-graphic information linked to the component in the model. No need for detailed graphics.							-Safety Information -Manufacturers' Operation Instructions -Manufacturer warranty Information -Original Vendor Information -Preventative Maintenance Schedules -Component Identification Numbers -Isometric Drawings -Material Specifications
	Reference general location of cooling units and duct lines. System will be represented with symbols to show approximate locations.							**None**
	*I have no maintenance activities related to the cooling systems.							**None**
Com	Management Tasks	400	350	300	200	100	NB	Non-Graphic Information

pone nt		0	0	0	0	0		
Distribution Systems	Pair air, water, or steam distributors to energy monitoring systems.							-Material Specifications -Operation Test Reports -Energy Usage and Cost Records -Component Identification Numbers -Electrical Diagrams
	Access fabrication details for repairs to system components.							-Fabrication Details -Isometric Drawings -Component Identification Numbers -Safety Information -Electrical Diagrams -Inventory of Replacement Parts -Material Quantities -Material Specifications
	Train maintenance staff on the layout and functions of the distribution systems.							-Isometric Drawings -Safety Information -Component Identification Numbers -Manufacturers' Operation Instructions
	Demonstrate compliance of distribution system in meeting safety and building codes.							-Building Permits -Operation Test Reports -Inspection Reports -Manufacturers' Operation Instructions -Safety Information -Component Identification Numbers
	Conduct preventive maintenance or repair maintenance on pumps, fans, lines, or other mechanical components.							-Inspection Reports -Inventory of Replacement Parts -Component Identification Numbers -Safety Information -Preventative Maintenance Schedules -Material Quantities -Material Specifications -Operation Test Reports
	Map exact location of components when planning for facility							-As-Built Drawings -Isometric Drawings -Safety Information

	renovations.							-Electrical Diagrams -Component Identification Numbers
	Locate pumps, fans, motors, or other components for repair in the event of failure.							-Material Quantities -Material Specifications -Fabrication Details -Safety Information -Electrical Diagrams -Component Identification Numbers -Manufacturers' Operation Instructions -Manufacturer warranty Information -Original Vendor Information
	Conduct scheduled inspections on distribution components.							-Component Identification Numbers -Preventative Maintenance Schedules -Operation Test Reports
	Map approximate locations of distribution components when planning for demolition of facility components or structure.							-Safety Information -As-Built Drawings -Electrical Diagrams -Component Identification Numbers
	Only need non-graphic information linked to the component in the model. No need for detailed graphics.							-Safety Information -Manufacturers' Operation Instructions -Manufacturer warranty Information -Original Vendor Information -Preventative Maintenance Schedules -Component Identification Numbers -Isometric Drawings -Material Specifications
	Reference general location of system. System will be represented with symbols to show approximate locations.							**None**
	*I have no maintenance activities related to the distribution systems.							**None**

	Management Tasks	400	350	300	200	100	NB	Non-Graphic Information
Instrumentation and Controls	Pair instruments and controls (thermostats and actuating valves) to energy monitoring systems							-Material Specifications -Operation Test Reports -Energy Usage and Cost Records -Component Identification Numbers -Electrical Diagrams
	Train maintenance staff on the operation and functions of the instruments and controls.							-Isometric Drawings -Safety Information -Component Identification Numbers -Manufacturers' Operation Instructions
	Demonstrate compliance of instruments and controls in meeting safety and building codes.							-Building Permits -Operation Test Reports -Inspection Reports -Manufacturers' Operation Instructions -Safety Information -Component Identification Numbers
	Conduct preventive maintenance or repair in instruments and controls							-Inspection Reports -Inventory of Replacement Parts -Component Identification Numbers -Safety Information -Preventative Maintenance Schedules -Material Quantities -Material Specifications -Operation Test Reports -Electrical Diagrams
	Map exact location of components when planning for facility renovations.							-As-Built Drawings -Isometric Drawings -Safety Information -Electrical Diagrams -Component Identification Numbers
	Locate instruments and controls for repair in the event of failure.							-Material Quantities -Material Specifications -Fabrication Details -Safety Information -Electrical Diagrams -Component Identification Numbers

								-Manufacturers' Operation Instructions -Manufacturer warranty Information -Original Vendor Information
	Conduct scheduled inspections on instruments and controls							-Component Identification Numbers -Preventative Maintenance Schedules -Operation Test Reports
	Map approximate locations of controls and instruments when planning for demolition of facility components or structure.							-Safety Information -As-Built Drawings -Electrical Diagrams -Component Identification Numbers
	Only need non-graphic information linked to the component in the model. No need for detailed graphics.							-Safety Information -Manufacturers' Operation Instructions -Manufacturer warranty Information -Original Vendor Information -Preventative Maintenance Schedules -Component Identification Numbers -Isometric Drawings -Material Specifications
	Reference general location of instruments. System will be represented with symbols to show approximate locations.							**None**
	*I have no maintenance activities related to the controls and instruments.							**None**

Data Used in this Worksheet are courtesy of:

UNIFORMAT II

Contributing Mechanical Contractor

BIMFORUM Level of Development Specifications 2013

Air Conditioning Contractors of America

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