Innovative Uses of BIM for Facility Management

A Major Qualifying Project Submitted to the faculty of

Worcester Polytechnic Institute

In partial fulfillment of the requirements for the

Degree of Bachelor of Science in Civil Engineering by

Kristen D. Hunt
Juan D. Torres Betancur

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Abstract

The goal of this project is to contribute to the improvement of the facility management operations for the Massachusetts Port Authority by streamlining the handover process and optimizing asset operations. This project contributes to the gradual improvement of the facility management functions at Massport by extending the current use of Building Information Modeling (BIM). This project enriched the BIM models of the Framingham Parking Garage facility and created a template to help investigate better practices for data attainment. Information collected was incorporated into the existing BIM model to facilitate future operations of maintenance. It also explored potential improvements for the interoperability between BIM model and the Computer Maintenance Management System. Extensions for improved BIM interoperability with structural analysis were also explored.

Capstone Design Statement

This project used Building Information Modeling (BIM) technology to design an improved handover process for the sponsor, the Massachusetts Port Authority (Massport). Their four-story Logan Express Garage, in Framingham, Massachusetts was employed as the model for the case study and structural analysis. This case study looked into the structural engineering, construction, and facility management of this structure. The study included an investigation of existing processes and, based on needs, modified models to represent the product of the improved handover process. Guidelines were created for future implementation of the proposed process.

The structural analysis was both completed through hand calculations and also through the Robot Structural Analysis software application. The results were analyzed and compared to one another and conclusions were drawn. The structural review was conducted according to AISC design standards and the IBC building code, using the as-built structural models for this facility. The BIM model, originally created using Revit software, was imported into the Robot Structural Analysis application and adjusted so the program would perform the structural analysis. This capstone design addressed the realistic constraints of health and safety, social, economic, sustainability, and manufacturability and constructability, as discussed below.

Health & Safety: A structural analysis is crucial for the stability of a structure. Conducting in-depth calculations assure the correct geometry and materials are used to construct the building. The ultimate goal of engineering a building is to create a functional and safe environment for people inside and in the surrounding areas. Analysis of structural components is an important basic step towards the finished product.

Social: Constructing and designing structures create communities and locations for social interactions. The analysis of the loads, materials and distribution of space all have to consider the end purpose and the ways in which the structure will affect and be affected by the people using it. Massport has a social mission to serve the public which can be fulfilled through their structures, ports and facilities.

Economic: The economic aspect of an engineering project can be crucial to the success rate of the project. The structural analysis through BIM technology ensures that clash detections and material selections are done before the construction begins. This allows the project to foresee

problems and resolve them before construction has begun and costs are increased for changes. The interoperability also lends an economic perspective to the project because the improved collaboration allows for more efficient practices and decreased waste, by minimizing errors and omissions.

Sustainability: Improving the handover process creates a more sustainable means of working. Current methods waste time and resources and are not modified for successful operations. The facility management personnel are the people who maintain and assure that the structure is maintained, with the proper information and models, the process would be more sustainable and efficient. Improving the process to include the handing over of completed electronic models also reduces large hard copy files, creating a more environmentally sustainable practice.

Manufacturability & Constructability: The use of BIM technology on projects has further increased the precision in the quantifications of materials used and predictability of problems that may occur under construction processes. This use of BIM has also changed the way in which a structural analysis can be performed. Software, like Robot Structural Analysis, allows for improved construction because the design can be reviewed by construction staff prior to the initiation of on-site construction.

Professional Licensure Statement

As a student studying in the major of civil engineering, the ultimate goal is to work in the design and construction of civil engineering projects and move up the career ladder acquiring additional knowledge and professional experience and also developing mature judgement in the field. The Professional Engineering Licensure certifies that this process has taken place after some time of professional practice. To achieve this, several steps must be taken. The first of which, after completing the required courses and obtaining a degree at an ABET accredited institute, is to pass the Fundamentals of Engineering Exam (FE Exam). The exam covers various material related to the field and information to assure a successful engineer in the workforce. Upon completion of the coursework and exam the individual demonstrates possession of the engineering fundamentals that will allow him/her to start his/her professional experience. To become an eligible professional engineer, a person must gain four years of professional experience, either in a qualified position or at graduate schooling.

Once passing the FE exam and gaining four years of experience, an engineer may apply to obtain his/her Professional Engineering License (PE). With a PE license a professional would be able to take on new responsibilities. The license allows the person to gain authority and responsibility for design work. Throughout the individual's career, he or she must continue to hone his or her skills to progress through the ranks and to maintain quality work. There are requirements to sustain the professional license officially as well, such as attending events and continuing studying, in addition to specific state guidelines.

The importance of the professional licensure is evident in several different situations. The professional licensure allows an engineer to legally sign and submit engineering drawings or plans. Due to this legal constraint, any engineer that would like to progress their career would need to receive professional licensure for certain jobs of high responsibility. This also emphasizes that professional engineers are responsible for the lives of those affected by his or her work. Because there is a knowledge and skill set requirement for receiving a professional license, the standards of competency of each engineer is also improved. This is extremely important as it ensures the public that an experienced and knowledgeable individual is responsible for the many projects that affect not only private sectors but also the public.

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Authorship

The entirety of this project was completed through teamwork and collaboration. Both team members were responsible for editing and review all components of the report and project. Specific sections which had a primary author are designated below.

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1.0 Introduction

The Architecture, Engineering and Construction Industry has been gradually changing with the implementation of Building Information Modeling (BIM). The construction industry has seen an increase from 28% to 71% in usage from 2008 to 2013 (McGraw-Hill Construction, 2012). BIM increases communication and organization while decreasing the inefficiencies of the industry such as unplanned difficulties with processes and interfering components. The implementation of the enabling technology of BIM allows companies to see "faster project approvals, increased positive client interactions and higher client satisfaction" (Gaudiosi, 2015). The programs and uses of BIM are continually advancing to include new applications and purposes.

BIM is valuable to numerous professions throughout the lifecycle of a building. It is employed for the design, construction, operation and renovation phases for any given building or structure. Multiple BIM-based software applications have been developed to provide for the needs in each of the project phases and professions. Specific programs highlight and focus the needs for the particular function. Between phases the models and information must be exchanged between different professionals and also possibly different software. This interoperability on data exchange, like other aspects included in BIM, is also improving throughout the building lifecycle and it is being researched in the search for efficient practices.

The handover process between the construction phase and the operation and maintenance phase of the building can contain large amounts of information that have value to different people. The excess of information that is needed for long-term facility use is referred to as the "tsunami" effect, as seen in Figure 1 below.
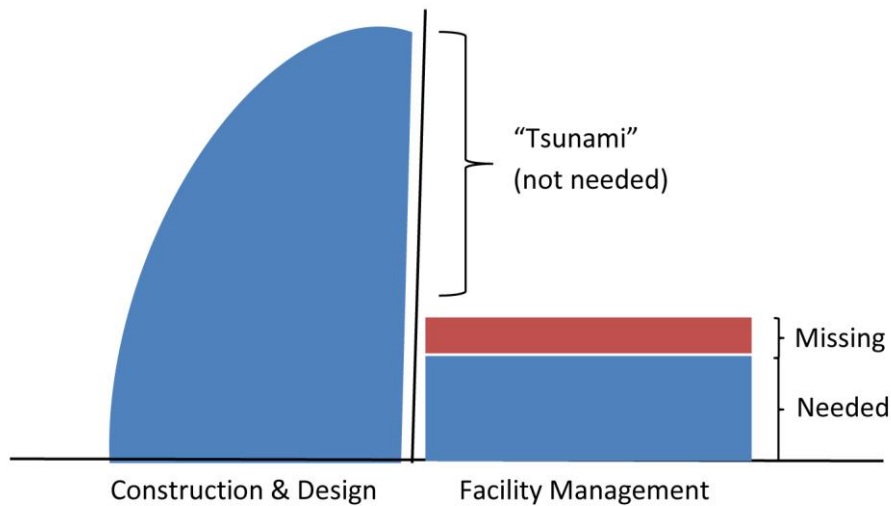
Figure 1: The "Tsunami" Effect (Adapted from Foster, 2011)

All of this extra information, from the perspective of the facility manager, is the tsunami that has to be cut down and refined to accommodate the needs for maintaining the building. The remaining information still useful to the facility management process is the blue rectangle on the right half of the figure above. On the other hand, some information needed for the processes after the completion of the building may not be included in the model handover because it was not originally vital for the design or construction; the red area in Figure 1 represents this. Therefore, it would have to be added to the model to support the needs of the facility management team.

Massport, the owner and operator of various transportation systems across Massachusetts and the sponsor for this project, has previously created a BIM roadmap. This roadmap outlines future BIM applications and processes to be implemented in Massport's facilities for the desired result of a completed BIM portfolio. The steps for implementation will be to normalize BIM-based project management, optimize asset management, and institutionalize enterprise asset management. The specific concept from the roadmap addressed for this project is to "optimize BIM to FM-integrated asset management" (Massport, 2015c)

Considering the "tsunami" effect and the Massport BIM roadmap, the project goal is to improve efficiency of Facility Management operations for Massport by streamlining the handover process and optimizing asset operations.

To address this goal, the team refined and prepared BIM Models to more efficiently serve FM in the operations and maintenance throughout the building's lifecycle. The model was

refined according to the determined   needs of the FM division. Further guidelines were distinguished to improve the handover process to aid FM, and research was conducted to investigate practical software programs to improve efficiency of asset operations.

The project resulted in a modified model with the desired attributes, guidelines for a streamlined handover process, and research of BIM-FM integration systems.

2.0 Background

This literature review provides background knowledge and details to better understand the concepts and processes of BIM and its applications. This chapter provides an overview on Massport's history and their current implementation of BIM, along with information on the current uses of BIM software in the design, construction, and facility management phases of a building.

2.1 Building Information Modeling

Building Information Modeling (BIM), is a concept used to incorporate the information and data for a building into an interactive model created on software. According to National BIM Standard (NBIMS), "a building information model is a 3D digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward" (NBIMS, 2015).

Building information modeling is not necessarily a new technology but in recent years numerous new applications with BIM have come about. "The adoption of BIM has grown from 28% to 71% in the construction industry between 2008 and 2013 in the first and second BIM SmartMarket Report research studies, published by McGraw-Hill Construction in 2006 and 2009" (McGraw-Hill Construction, 2012). BIM has a wide range of uses for professions across fields of practice. BIM can be used for the design, construction, and maintenance and operation of the building. The graphic below in Figure 2 displays the uses of BIM throughout the life of a building.

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Figure 2: BIM through the lifecycle of a building (Syncronia, 2011)

The architect may use BIM to initially design the building before construction. The civil engineer or structural engineer will take the design and continue using the BIM process to design the structure and materials needed for a stable building. Along the way other engineers, such as mechanical or electrical, may perform analyses, such as energy loss and orientation on the site. BIM programs can also be used in construction project management for the cost and constructability analysis, as well as scheduling. After the model is developed to complete construction, the model could be transferred to support the operation of the building. The model can continue to be further modified multiple times in the case of renovations. BIM is a valuable asset for the lifecycle of the building. BIM integration with Computerized Maintenance Management System (CMMS) software is also a valuable concept that is discussed in 2.3.3.

Models are made by numerous professionals and for different purposes. During creation and after completion the product is modified for each use, not only is the content and software specific but also the amount and formation of information is geared towards the function of the model. The amount of information or detail in a model can be referenced through the Level of Detail. There is also a Level of Development, which "is the degree to which the element's geometry and attached information has been thought through- the degree to which project team members may rely on the information when using the model" (BIM Forum, 2013). Levels of Development are classified on a number scale and different levels along the scale represent specified descriptions for the corresponding details or development. These levels are defined as 100, 200, 300, 400, and 500. Level 0 signifies an item not modeled, level 100 refers to a

conceptual model, and level 200 is a generic or representational model and the details increase in amount, value and accuracy as the levels increase. Level 300 includes accurate information and dimensions, and level 400 also includes fabrication, assembly and detailing information. Level 500 would correspond to a record model (Burdi, 2011). Examples of the Level of Detail and Level of Development can be viewed in Figure 3 below (McPhee, 2013).
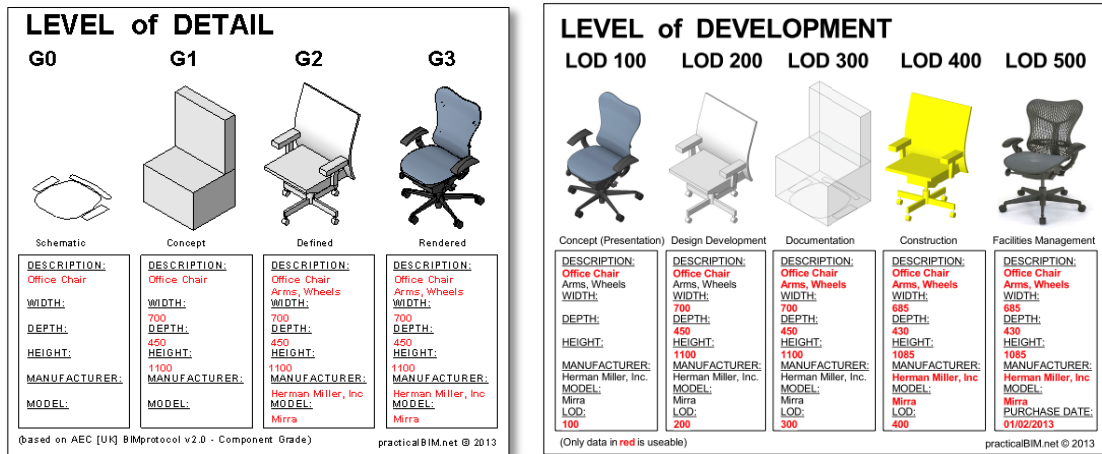
Figure 3: Level of Detail and Level of Development Examples (BIM Forum, 2013)

Over the years organizations have created ways to attempt to make BIM more useful and standardized. Codes and standards of use have been devised across the globe. The ultimate purpose of these standards is to allow a normalized process and product for all BIM as to allow easier communication and compatibility. One such organization is OmniClass, which is "a standard for organizing all construction information" (OmniClass, 2015). Another well-known set of codes is the Construction Operations Building information exchange, or COBie. The goal behind the creation of COBie is to assure that the information required is carried through the lifecycle of a building, including facility management, in a way that it can be productively employed (East, 2012). In some areas around the world these standards are required, like in the United Kingdom, however elsewhere the normalized standards have not been as strongly enforced so there still remain discrepancies from model to model.

2.2 Massport

The project is sponsored by the Massachusetts Port Authority, commonly known as Massport, at Boston Logan International Airport. Massport is an independent public authority

dealing with transportation means throughout Massachusetts. As any organization responsible for facilities or buildings, in the modern technology age, Massport has turned to innovative technologies for efficient operation. The following sections will describe Massport as an organization, as well as its current BIM applications and future endeavors.

2.2.1 Massport Overview

Massport was established in 1956 and became operational on February 17, 1959. It was created as an independent public authority as not to draw funds from the government or the taxpaying people. At the time of its creation, it was able to fund and sustain itself through "the sale of revenue bonds, charges to users of its facilities and income from investments" (Massport, 2015a). Today Massport is "a world class organization of people moving people and goods – and connecting Massachusetts and New England to the world – safely and securely and with a commitment to our neighboring communities" (Massport, 2015b). Boston Logan International Airport, Worcester Airport, Hanscom Field, Port of Boston and numerous other properties, such a Logan Express parking garages, are under Massport's jurisdiction.

Logan International Airport, located in Boston Massachusetts, provides flights to more than 100 countries and areas around the world through the collaboration with nearly 50 airline companies (Massport, 2015b). First opened in 1923 and officially named the General Edward Lawrence Logan Airport in 1943, the airport has had numerous expansions and advances in its field through the ninety plus years (Massport, 2015a). Logan Airport currently has four terminals and local parking garage structures. The most recent completion to the complex at Logan Airport is the parking garage facility.

The facility specifically incorporated in this project is the Logan Express parking garage located in Framingham, Massachusetts. This garage consists of four stories of parking with 1100 parking spaces and a terminal with a passenger waiting area. The location was opened in April of 2015 (Benson, 2015).

2.2.2 Massport's Implementation of BIM

Recently, Massport has been implementing various applications and uses of BIM through different stages of the project development. Models have been created of the new constructed parking garage and one of the terminals. These models were developed following the completed

construction to represent the as-built situations. However, they have not been adapted for facility management use. Before these models are refined for the utilization in the operations of the building, the proper information and attributes of certain components have to be collected. Massport is working with two companies using three different techniques to gather the desired attributes that will be included in the model for facility management (Burdi, Personal Communication, 2015). In the past years, facility management teams at Logan Airport have been operating with IBM Maximo.

2.2.3 The Future of Massport with BIM

Massport has created a Massport Building Information Modeling Roadmap for the current and future implementation of BIM. The roadmap explains key areas where BIM can improve throughout Massport. Massport's mission for BIM is stated below:

> "Massport will utilize BIM and related technologies to empower its staff and service providers to design and build outstanding structures, and then manage and sustain these facilities and assets to meet Massport's mission. As stewards of these digital assets, Massport will maintain BIM,GIS, and facility maintenance asset data to support strategic planning, sound decisions, sustainability, environmental responsiveness, and improved processes to add value to managing the building lifecycle, and to aid Massport in better reinvestment of available funds based upon organizational missions and operational requirements" (Massport, 2015c).

Down the road, the ideal result for Massport would be to have a BIM portfolio of digital models for all facilities fully complete with reliable data and access to personnel to maximize efficiency. Steps along the way included in the roadmap are:

- "Normalize BIM based project management and project management training,
- Optimize BIM to FM- integrated asset management,
- Institutionalize enterprise asset management" (Massport, 2015c).

These three steps are to be accomplished through smaller steps outlined on a timeline spanning from 2014 to 2020 within the roadmap.

2.3 BIM-FM Integration Software

Throughout the history of computer aided building design, the programs, applications and software have continued to specify and improve for different reasons. All components of the design, construction and operation of a building can be documented and displayed through software. Depending on the need of the user and purpose of the information, certain types of programs are more suitable than others. This section explores the software of BIM, FM and integrators: their purposes, features, benefits and capabilities.

2.3.1 BIM Software

The different sectors of construction require specialized BIM software, and although many are compatible with each other, each software program is not interchangeable. This section will focus on widely used BIM software programs in architecture, MEP (mechanical, electrical, and plumbing), structures, and construction. All of these programs create data for the final BIM project and thus, it is very important to understand the common uses and capabilities of these programs.

2.3.1.1 Architecture

There are two very popular architecture programs used in the construction industry. Each has different functionality but tend to reach a similar conclusion with the product. The first that this section will cover is Revit Architecture by Autodesk, and then ArchiCAD by Graphisoft.

Revit Architecture focuses on the capability to create different architectural features such as a curtain wall, floor, roof, room and area, stairs, anti-aliasing and loadable component for design. The primary use of Revit Architecture is for a firm to create a 3D representation of the model that they believe the owner is visualizing. Since this software is from the Autodesk family, it is easily transferred into other Autodesk programs such as: Revit MEP, Revit Structure, and Navisworks. This program is made to be flexible with the design features. It is designed to allow the user to easily fix wall joints and the loadable components such as doors and windows. Revit Architecture also has a layout of phase and phase filters. This allows the user to easily see the process of either demolition or construction. Its 3D feature is axonometric as well, which constricts the ease of virtually walking around the building or structure designed (AE, 2013).

Although ArchiCAD is similar to Revit Architecture in that it focuses on the designing of a structure for an owner, ArchiCAD has a more intuitive layout for its commands. It has perspective views that embrace the option to virtually walk around the designed structure. There are also drafting tools that easily incorporate the option of elevations and sections, and the energy modeling systems work well. However, the energy modeling is not as powerful as the Ecotect and Green Building Studio from Revit Architecture (AE, 2013).

For the most part, there are advantages to each. While ArchiCAD has working templates that do not leave the user starting from the creation of templates and standards, Revit Architecture can easily convert to AutoCAD, and this is the program most widely used in the industry. In Figure 4 and 5, below, you can see side-by-side comparisons of the layout for both Revit Architecture and ArchiCAD.

Figure 4: Revit Architecture Interface (Autodesk, 2013)
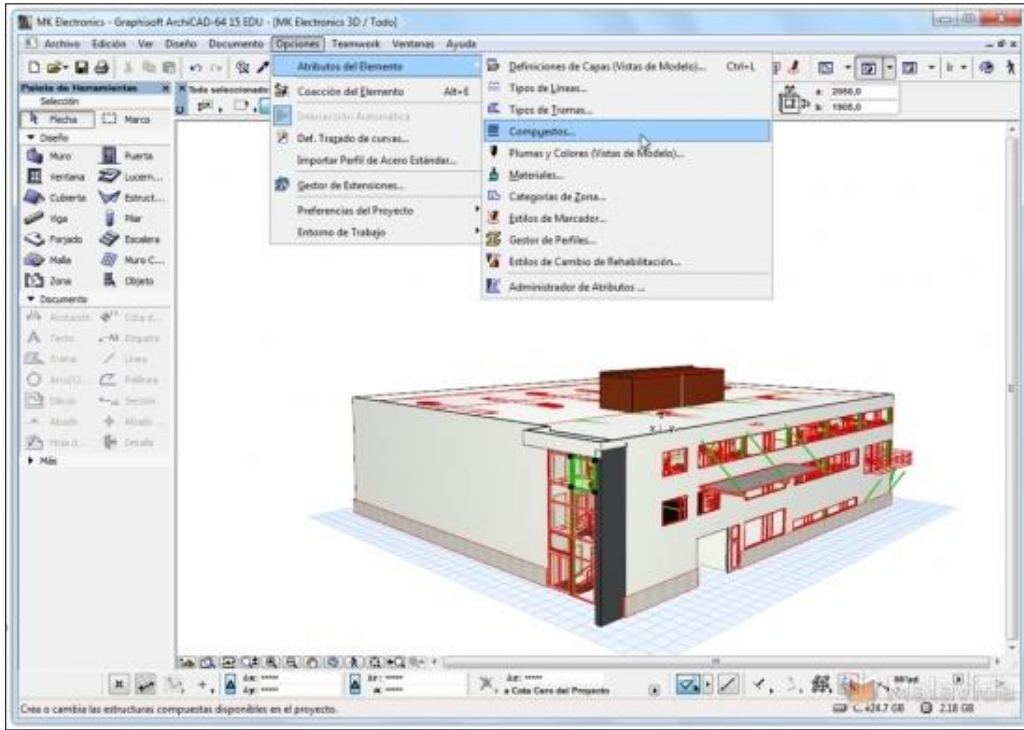
Figure 5: ArchiCAD Interface (ArchiCAD, 2015)

2.3.1.2 MEP

MEP stands for mechanical, electrical, and plumbing. This important component of a construction project is often coordinated through collaboration in BIM because of the visualization capabilities of the BIM models. The models can help each line of work find clashes in the design of the mechanical, electrical, and plumbing systems. This allows foresight in the designing process since the clash is detected before the construction is undertaken, effectively reducing related costs and time.

Two popular programs for this kind of coordination are Autodesk Revit MEP and Bentley Hevacomp Mechanical Designer. Both focus on the MEP coordination and energy analysis of a design but have different layouts that end up affecting the learning curve of the software.

Revit MEP follows the same interface as the other Revit software programs. This allows a user who is familiar with the other Revit software programs to easily understand and use the MEP program. The main purpose of the MEP version is to "help mechanical, electrical, and plumbing engineers keep design data coordinated, minimize errors, and experience enhanced

collaboration with engineering and architecture teams (Autodesk, 2015a)." The interface of the software allows the different members of the MEP team to see each other's drawings. It also features "automatic sizing and flow calculation for maximum performance (Autodesk, 2015a)." This program also coordinates with Revit Architecture and Revit Structures which means there are never issues with converting data amongst the different software.

Another popular MEP software program is Bentley Hevacomp Mechanical Designer. This software focuses on "engineering-quality building load and energy calculations (Bentley, 2015)." This is accompanied by duct and pipe systems. The model utilizes DXF files and includes 3D visualization tools. One of the differences between this software and Revit MEP is that it includes code checking. This code checking is available for building designs and can be changed to be country specific (Bentley, 2015). Figures 6 and 7 below illustrate the visual differences between using Revit MEP and Bentley Hevacomp Mechanical Designer, respectively.

Figure 6: Revit MEP Interface (Cantonese, 2014)
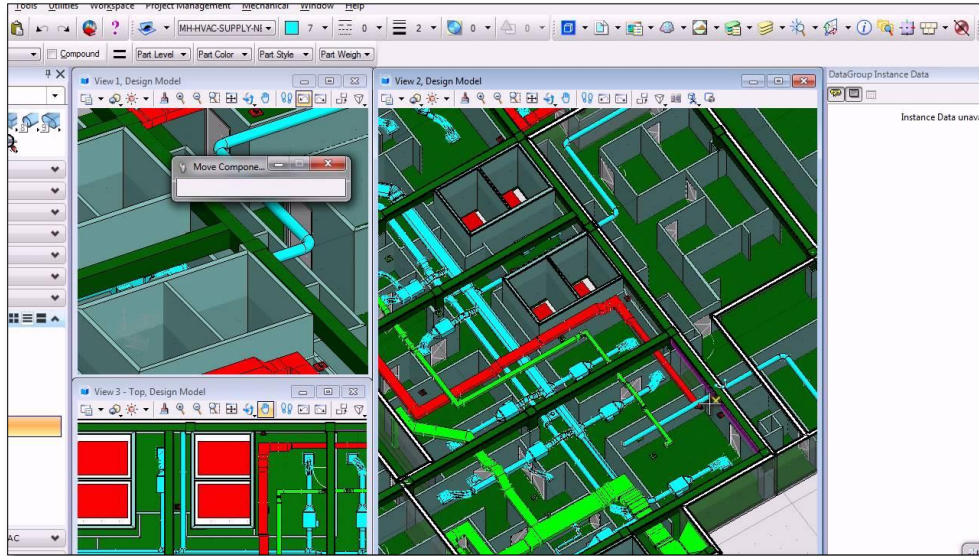
Figure 7: Bentley Hevacomp Interface (Cortes, 2012)

2.3.1.3 Structure

The structural analysis of a project has been evolving with the introduction of BIM structural capabilities. Not only can projects be designed through BIM software, specifications of materials, dimensions, and structural analysis can also be incorporated into the construction and design phase. Two programs that work on this structural field are Autodesk Revit Structure and Tekla Structures.

Autodesk Revit Structure is another version of the Autodesk family. As with the other Revit programs, there is smooth interoperability between Revit Structure and other Revit programs such as Revit Architecture and Revit MEP. The addition of Robot Analysis makes Revit Structure very capable analysis software. The Robot Analysis is the extension that allows Revit Structure to perform the structural analysis of a given project. Revit Structure also focuses on the ability to create engineered beams and project-unique components. This asset gives the user the flexibility to engineer complex projects. The Revit interface for Revit Structure also improves the capacity to engage in large project files. Figure 8 below shows the interface of Revit Structures.

Figure 8: Revit Structure Interface (Autodesk, 2011)

Tekla Structures is another structural analysis and design software. Although it is not part of the Revit family suite, it does have extensions for interoperability with Revit models. This allows the software to work with Revit Architecture and other models of the sort. Tekla Structures also prides itself in the open BIM approach that enables users to use IFC's to work with different software programs (Tekla, 2015a). Figure 9 below shows the interface of Tekla Structures.

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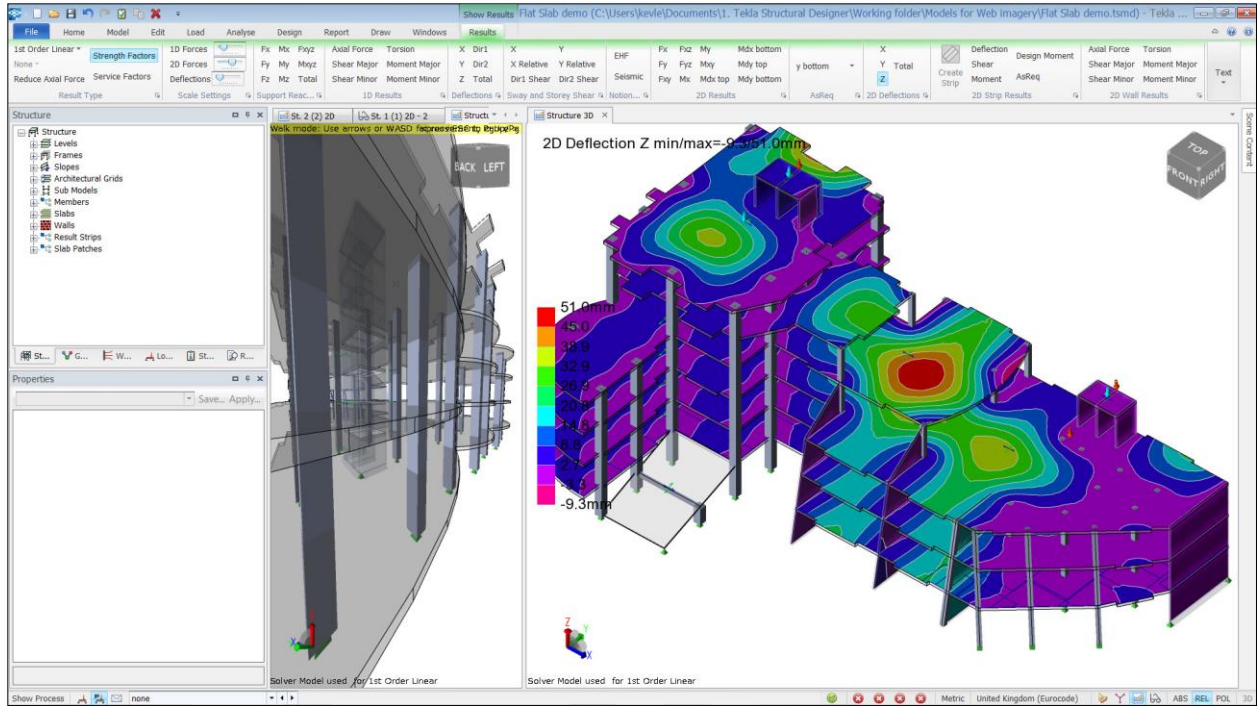
Figure 9: Tekla Structure Interface (Tekla, 2015b)

2.3.1.4 Construction

Two well-known construction software programs are Autodesk's Navisworks and the Solibri Model Checker. The main objective of the two software is to avoid construction design mistakes while assuring quality of the project. By using features such as "clash detections" in Navisworks and "code checking" in Solibri, users are empowered to not only detect possible problems, but visualize and seek solutions to these problems. Early detections empower firms to avoid problems that can cause expensive fixes and lengthened project durations.

The purpose of the Autodesk Navisworks program is to "help enable coordination, construction simulation, and whole-project analysis" (Autodesk, 2015b). The program is used to optimize scheduling, detect clashes and have constant collaboration amongst the different trades working on a project. Navisworks is also designed to be able to handle large project files and many different file formats, unlike Solibri Model Checker's need for IFC's. Figure 10 below illustrates the interface of Navisworks.

Figure 10: Navisworks Interface (Graphic Design Inc., 2012)

Solibri Model Checker allows BIM models to be checked for "potential problems, conflicts, or design code violations, and also includes visualization, walkthrough, interference detection, model comparison, and information takeoff capabilities" (Khemlani, 2012). The 2012 release of this software includes the capability to automatically select relevant tasks and rulesets. It can also provide a "result summary" for an overview of where most issues can be found. Another useful addition is the ability to customize rules and code check the structure with any new set of rules. In respects to interoperability, Solibri Code Checker can support COBie data importation for visualization (Khemlani, 2012). Figure 11 below illustrates the interface of Solibri Code Checker.

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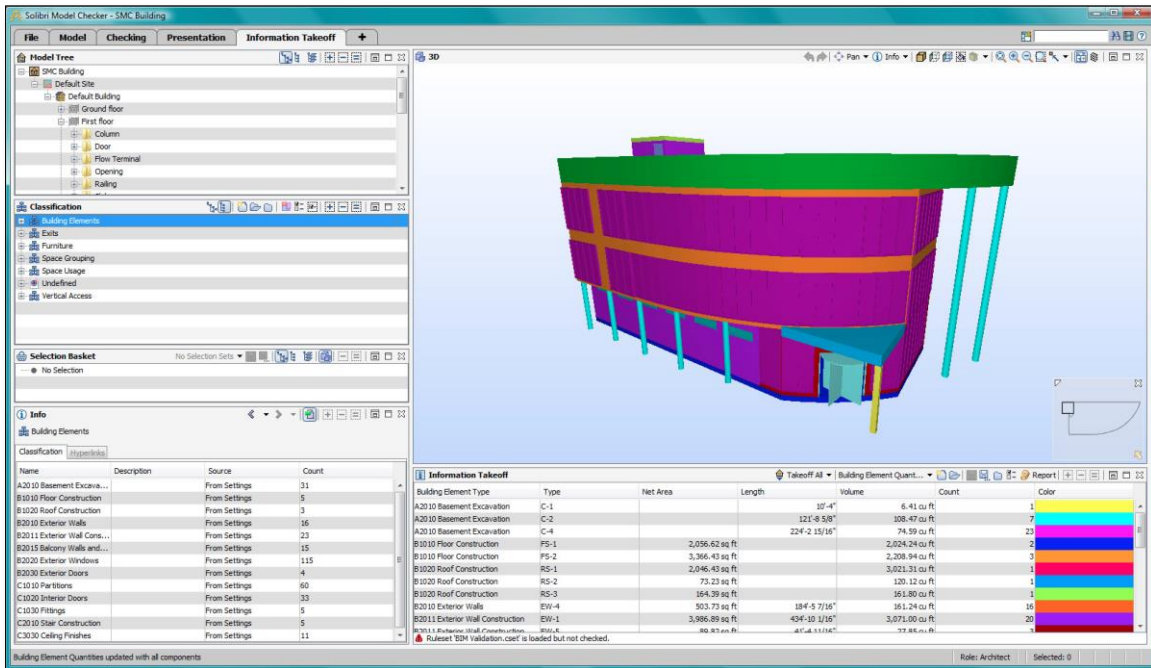
Figure 11: Solibri Code Checker Interface (Khemlani, 2012)

2.3.2 FM Software

Once a building is complete it enters into the operation and maintenance phase of its lifecycle. During this time software is employed to assure the smooth operation of the building. This includes maintenance and repairs, inventories, work orders and many more applications. Software with the purpose of operating the building is commonly referred to as Facility Management (FM) or Computerized Maintenance Management Systems (CMMS). These software programs contain the information needed for maintaining a building after completion. Many of the FM and CMMS software also have applications built into the system to efficiently access and use the information.

IBM Maximo Asset Management is very commonly used software in the field of facility management. Maximo is applied to manage all aspect of facility management processes, which include asset, work, service, contract, inventory and procurement (IBM, 2015). The software contains all the information related to the items and objects throughout the building. Maximo is a web-based CMMS program, as seen in Figure 12, which can be accessed through a computer and connected to email to send work orders.

Figure 12: Maximo Interface (PRWeb, 2015)

2.3.3 Integration Software

Integrative software combines various types of software, such as BIM and FM programs mentioned above. The purpose of combining and integrating the separate programs used in a building is to assure all the information is included and it is conveniently located in a centralized location. By combining FM programs with BIM software, the details of objects are also given a location in the building through the 3D models. Examples of integrative software are EcoDomus, BIM 360 and YouBIM. Many integrators are located on the cloud so multiple copies can be investigated amongst numerous people on different devices and the information is kept synced and up to date.

2.3.3.1 EcoDomus

"EcoDomus software provides 3D view of facilities in an easy-to-use format for facility managers that links BIM with real-time facility operations data acquired via meters & sensors (Building Automation Systems, BAS) and facility management (FM) software" (EcoDomus,

2015). EcoDomus has multiple products, one of which is EcoDomus FM. This software focuses on assuring the information of the construction and design phases are accurately represented in an integrated model for the use in facility management. The program can track work orders and give a visual inventory to the user. EcoDomus is compatible with Autodesk Revit and Maximo, two extremely popular platforms, and it employs both COBie and OmniClass standards and codes (Starkov & Griffith, 2011). The software is employed to "compare "As Designed" with "As Operated" and "As Maintained" for intelligent decision making" (Starkov & Griffith, 2011). The image below in Figure 13 shows the interface and information provided in a typical window of the EcoDomus FM software.

Figure 13: EcoDomus Interface (EcoDomus, 2015)

2.3.3.2 BIM 360

BIM 360 is produced by Autodesk, and therefore has desirable compatibility with the other Autodesk products. BIM 360 is a cloud based application which can integrate various models to aid in many steps in the lifecycle of the building. The different versions of the application and the specified purposes can be viewed in Figure 14.
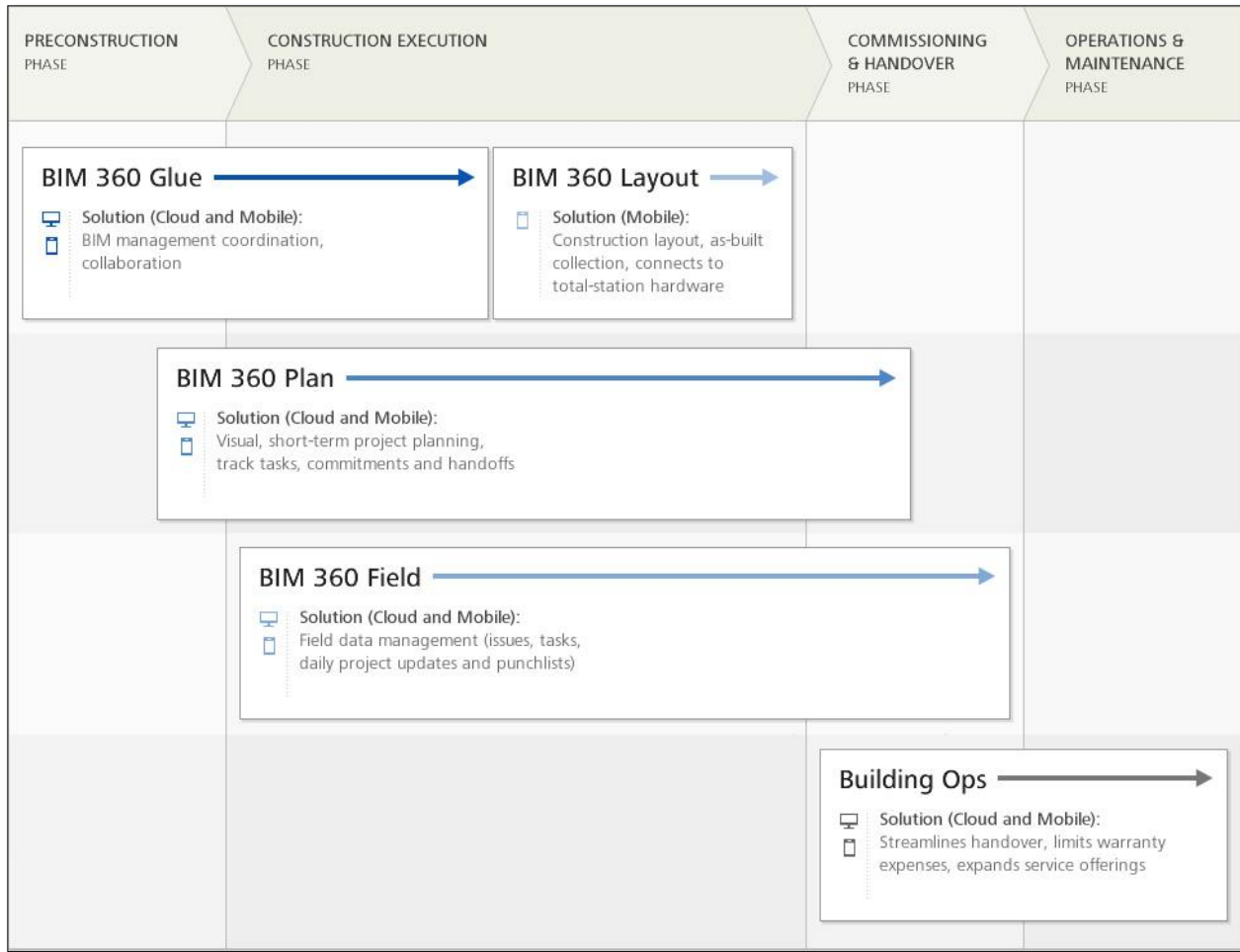
Figure 14: Version of BIM 360 (Autodesk, 2015c)

The application allows the user to easily access the information stored in each object simply by selecting it, and more information, such as orientation, distances and sizes, can be measured and determined in the 3D interactions. Like other integration systems, BIM 360 also provides the other views and plans of the building for gathering practical information and cross referencing details all in one software. The interface of BIM 360 can be seen on the iPad in Figure 15.

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Figure 15: BIM 360 Interface (CADTutor, 2012)

2.3.3.3 YouBIM

YouBIM is another application for integration that can be used across devices. YouBIM can connect and modify programs of a large variety from Revit, Maximo, Archibus and multiple different building management systems. YouBIM has the capabilities to show any version of the model which the user would need, whether it be the structural plans or just the HVAC systems or the layout of the lighting in a finished room. The application provides easy navigation through the 3D models and correspondences are made between 3D and 2D views to given a useful representation to the user. Each object contains all the information inputted into any of the systems for that particular item. Details such as instructions, warranties and videos can be stored and saved within the objects in their location in the model (ENGworks BIM, 2013). The program can also help the management team devise a preventative schedule and distribute work orders to allow a smooth operation. Figure 16 below displays the detailed model shown in YouBIM and the ease of access for the details of objects (ENGworks BIM, 2015).

Figure 16: YouBIM Interface (ENGworks BIM, 2015)

2.4 Innovated Concepts of BIM

The use of BIM has only recently started to become common jargon in the AEC (architecture, engineering, and construction) industry. Ten years ago very few companies were partaking in the use of BIM for their projects. As previously stated, the use of BIM in the construction industry was 28% in 2008 while it grew to 71% by 2013 (Alvarez-Romero, 2014). This leads to the idea that there should always be a focus on new and innovative concepts that could take the industry to the next leap. This section focuses on three new concepts that could lead to a change in the everyday work or efficiency of the industry.

2.4.1 Augmented or Virtual Reality with BIM

Augmented or virtual reality is a new technology that is able to create a digital space of models. This allows a user to not only visualize but immerse into the model. Some virtual reality programs can even allow the user to move objects and place them in new locations. In fact, this is exactly what McCarthy Building Companies is doing currently with their projects.

For a project in the Martin Luther King Multi-Service Ambulatory Care Center, McCarthy Building used virtual reality headsets to have the doctors and nurses overview the design and location of objects in the structure. This led to specific and knowledgeable feedback on the design of the structure. Mike Oster, the vice president and CIO of McCarthy, has stated that "when we started embracing VR in the design and building process, we began seeing faster project approvals, increased positive client interactions and higher client satisfaction (Gaudiosi, 2015)." Figure 17, below, illustrates the current use of virtual reality by McCarthy Building.

Figure 17: Virtual Reality Demonstration (Gaudiosi, 2015)

2.4.2 BIM Location Services

Location services for viewing a user's position have been limited to the user's ability to navigate through a 3D model or understand their own position in regards to a 2D floor plan. With the advancement of BIM models, BIM 360 Glue has been able to develop a way of combining the two methods for locating the user. With the introduction of a 2D Map to the 3D model, there is now a dropdown option for users to easily locate themselves on a floor plan and then click a location to interact with the 3D model. This is illustrated by Figure 18 below.

Figure 18: 2D and 3D Map Locations Services on BIM 360 Glue (Walker, 2015)

2.4.3 Construction Integrated for FM

The "tsunami" effect previously discussed is an effect of BIM in the construction processes. This effect is determined by the lack of information needed for facility management and overload of information created throughout the process of construction. This recurring theme has been acknowledged as a common problem in the industry and some studies have been made to describe possible solutions.

One of these studies was performed by Sergio Alvarez-Romero in 2014. His focus was on creating an approach for a "BIM-enabled digital handover process for enhancing the operation and maintenance of the facility" (Alvarez-Romero, 2014). This was done by analyzing the current practices and information needs for the handover process. Once this was determined, Alvarez-Romero proposed "an open standard approach for the creation of a Model View Definition that combines Industry Foundation Classes (IFCs) with COBie standards or with Owner defined standards." This would allow the information, created through a construction project, to be exported into usable templates for the facility management of the structure. This would make the handover process more efficient and increase BIM usage during the lifecycle of the structure. Figure 19 below shows the example case study that Alvarez-Romero created in accordance to his approach.

Figure 19: Model with Outlined Guideline Attributes (Alvarez-Romero, 2014)

2.5 Summary

The BIM implementations in the AEC industry have led to more efficient, leaner projects. Although there was reluctance to this innovation from traditional construction work, the vision of technology has brought new possibilities to the workflow and accuracy of construction. With the use of different software programs, such as Revit Architecture, Bentley Hevacomp, and Tekla Structure, the industry has focused on creating better visualization and forecasting of projects for the use of the construction phase and through the lifecycle of the project. With these advancements, however, there is now a stage of uncharted territory with the many choices of software programs.

The goal of this project is to contribute to the improvement of the facility management operations for the Massachusetts Port Authority by streamlining the handover process and optimizing asset operations. This project contributes to the gradual improvement of the facility management functions at Massport by extending the current use of Building Information Modeling (BIM). In the following section the methods are explored for the process and

completion of the project. To achieve this goal the team designated three main objectives which are the foundation for this Methodology Chapter:

1. **Enrich the current provided model to meet the requirements for the purpose of facility management.**

2. **Compile research of integration software to improve functionality for facility management use.**

3. **Conduct a structural analysis review of the existing garage through hand calculations and Robot Structural Analysis software.**

3.0 Model Manipulation

The first portion of the project was to manipulate and enrich the information content in the model to better aid in the facility management practices for operation of the garage, resulting in an improved model that would be handed over from the contractor to the facility management personnel. The model was analyzed to distinguish what information was already included and what was missing from the desired asset list needed for facility management. Once the assets' statues were identified, the model was enriched by adding objects and parameters to reflect the asset list. The final step was to export the refined model to a usable file format for facility management to view and query; in this case, Navisworks software was employed. The below sections explain in more detail the processes of fulfilling the three steps to manipulating the model.

3.1 Information Analysis

The first main objective was to distinguish the necessary and unnecessary attributes included and not included in the current provided models. The methodology for this objective is expanded on in the further subsections. The first step to reviewing the models was to request any and all current models for the Framingham Garage. This was done to ensure that the information reviewed was as complete as possible. The models received from Massport included As-Built and Record Models. These included Architectural Models, Structural Models, and MEP models. The As-Built Models were chosen for evaluation because these were the models that should have been most accurate to current facility conditions. Using the As-Built Models, which are the most accurate models to represent the building actually constructed, allowed the project to be reviewed with the information that is typically available during an actual handover process. Also important for the evaluation were the Facility Management practices being employed at Massport and the interactions with the models. The second part of the first objective was to differentiate the information that would be useful for facility management from the unnecessary information added on through construction.

3.1.1 Determine current status

The architectural model was chosen to be the main focus of the testing done for this part of the study. This model was chosen because it had the most objects and asset information. The central structural, MEP, and bulletin models were also linked to be able to have as complete a model as possible. Having all the models linked and in one place allowed an integrated visual representation of what information could be used by the facilities management team.

All models were created as Revit files, excluding DWG files for some objects used by subcontractors on the project which were not included in this study. All models used for this study had been created using Revit 2014 software and thus, each was updated for use in Revit 2016 software. All files also had to be extracted and stored on an external device, and a central file was created in order to edit and manipulate the models used.

3.1.2 Identify Facility Management information in model

To decide on the importance of information for the facilities management, Dr. Luciana Burdi and Willie Hicks were contacted. Dr. Burdi is the Deputy Director for Capital Programs and Environmental Affairs, and Willie Hicks is the Project Manager working on the asset management program at Massport. From the work that Willie Hicks had completed on the asset management program, he was able to create an excel spreadsheet with attributes or information that facilities management would need to make use of the models. This spreadsheet was given by Dr. Burdi.

The aforementioned excel spreadsheet, which can be partially viewed in Appendix B became the benchmark for determining the information that was needed from the existing BIM models to be useful for facilities management operations. This information ranged from assets like fire alarms and air conditioner units to water heaters and air flow meters. Each asset carried its own desired attribute list. An example of the assets and attributes is the duplex air compressor which had 26 different desired attributes. These attributes ranged from amperage to motor manufacturer to model number.

These asset and attributes list was then compared to the corresponding assets and the desired attributes in the BIM models. To more efficiently cross reference the information, schedules from the BIM models were created. These schedules, as seen in the guidelines in Appendix C, were organized to display the category, count, family, and type of each asset or

object in the model. This was used as the preliminary comparison between the information in the model and the information that the facilities management team wanted in the model.

3.2 Information Enrichment

To conduct the actual enrichment of the model itself, the team took different approaches based on the specific situation of each attribute. When an attribute in the list from facility management was not found in the model, it needed to be added by some means. The four methods for object addition were loading existing objects, downloading existing objects, modifying existing objects and creating new objects.

The first and simplest of the four options is loading an existing object. Attributes in this category were already contained in the component tab of Revit software or they were placed in the model previously. This method was used only when the object in the program was the proper representation of the listed attribute. Minor changes such as names and spelling for existing objects were carried out to assure the list matched the model sufficiently. An example of this is seen below for the object of the defibrillator.

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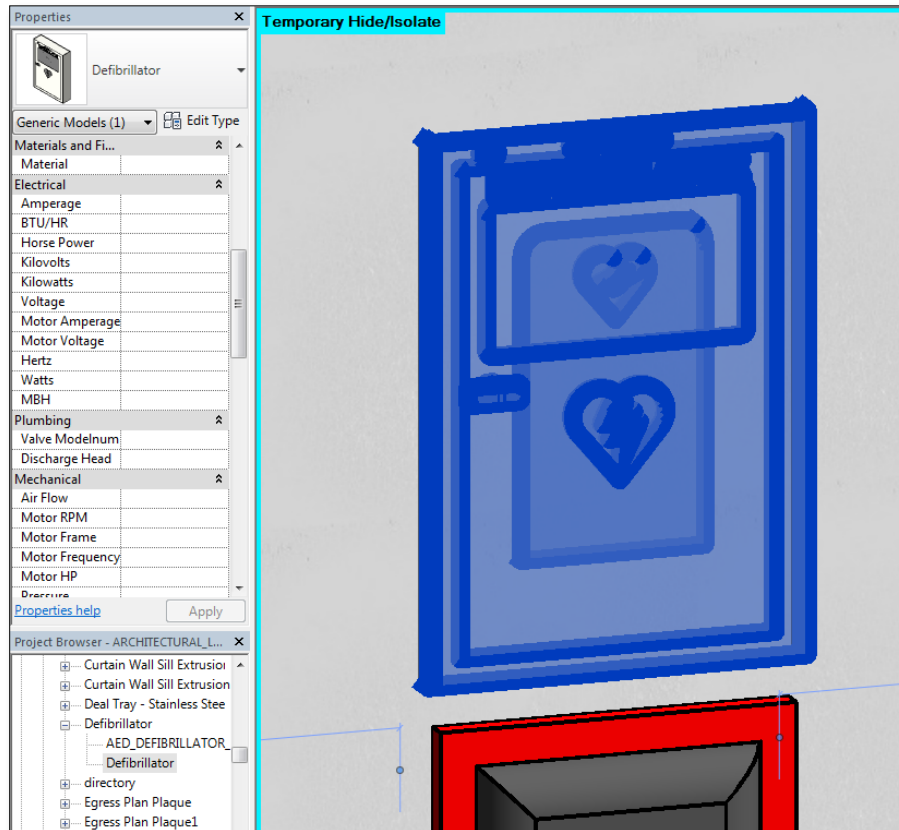
Figure 20: Example of Loaded Existing Object

Modifying existing objects was the most common method used. When the object was not in the model but an object in the same or similar family was found in the Revit library, then it was loaded and modified. Since most of the objects for the purpose of facility management acted as place holders and geometric shapes to hold information, the objects did not have to physically match the detail of the actual objects. Therefore, the team was able to modify the name, and family and categories when necessary, to assign the newly loaded object to the desired object from the list. This method was used for the majority of assets. This was especially true for objects of the same family such as panel board and air conditioner.
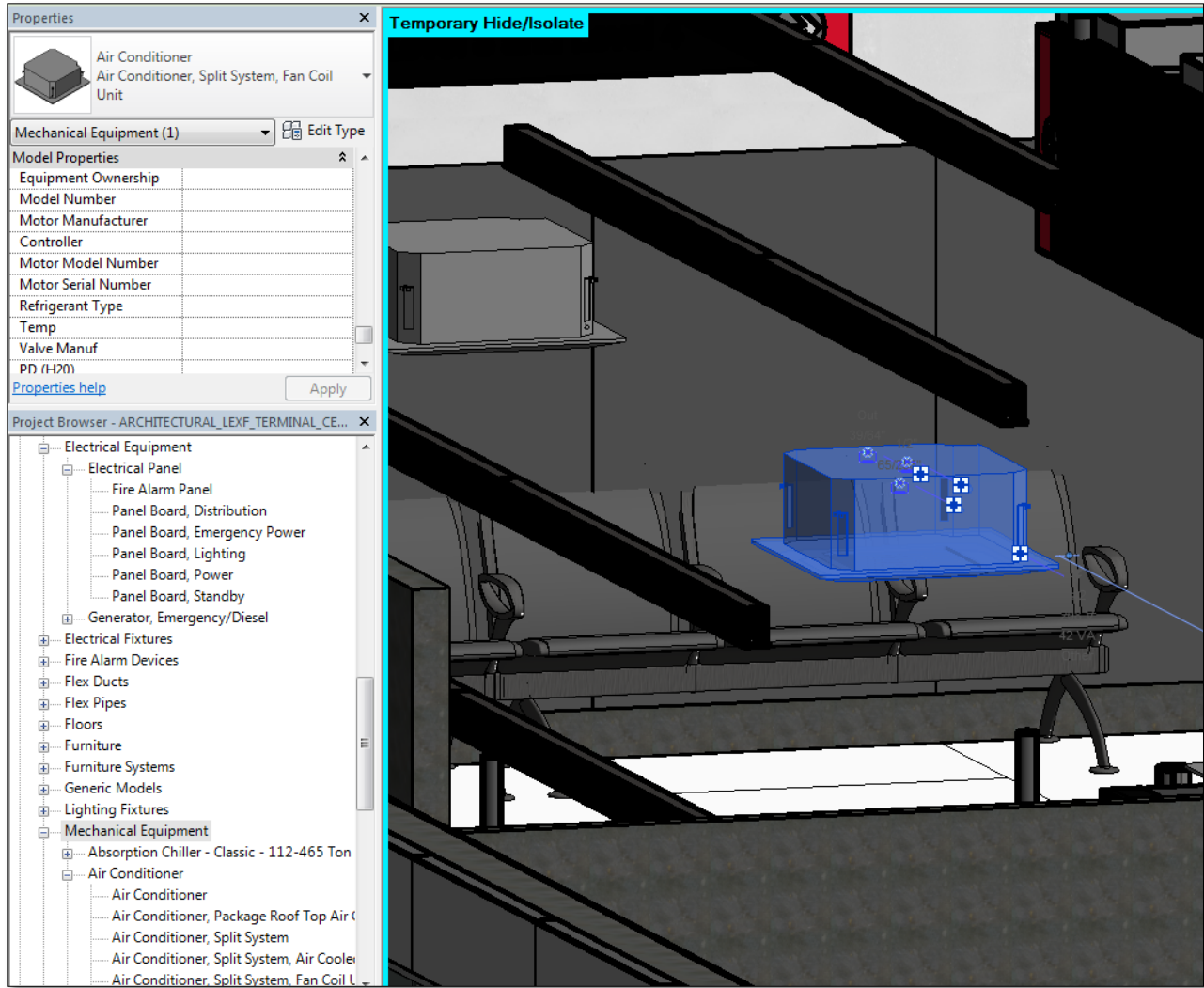
Figure 21: Example of Common Object

When an object was not located in the loaded components nor in the library of Revit, then it was downloaded from an external object library such as RevitCity. When the needed object was found, it was brought into the model and acted properly as any other object that would be previously placed in the model.

The final method mentioned above, creating new objects, was employed the least of the four for the refinement of the Framingham model. If an object listed on the desired asset lists was not in the model, the library or on an external database, it had to be created. To do this, simple geometry such as cubes were employed since the objects are place holders with LODs of 100 containing the crucial information for management of the space. The object was created in

AutoCAD and imported into the Revit library with the needed name, category and family to assure success for the end product.

Once all the necessary objects identified on the facility management asset list were added to the model the correct parameters and attributes were assigned to each. To do this, parameter fields were created before they could be attached to object families. Each parameter would appear when an object was selected and it would show a field next to the title of the parameter to provide a space to enter in the specific data for that object selected.
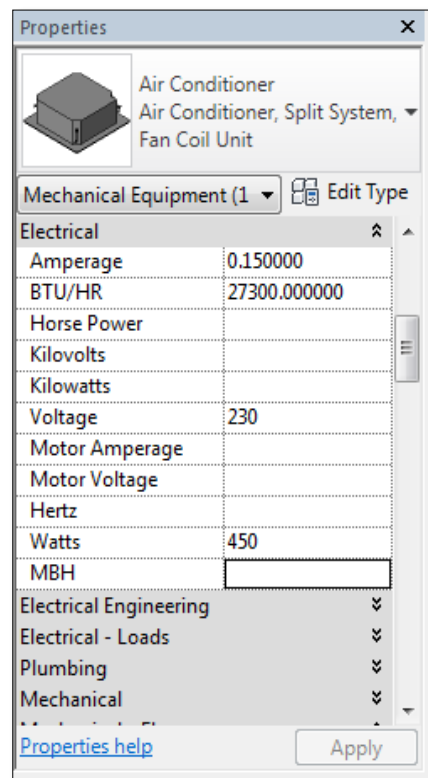
Figure 22: Properties of Selected Asset after Attributes were added

For each unique parameter listed in the asset list, a parameter field was created. Through the "Shared Parameters" function in Revit, the name and type of entry for the parameters were designated. Once created, the parameter was then assigned to the appropriate categories for the objects it had to identify. Also in this step, it could be designated under which section of the object properties the parameter would be located. In Figure 23, below, the "Shared Parameters" function is being used to add a parameter. The figure is adding the manufacturer parameter to the Shared Parameters list. Figure 24
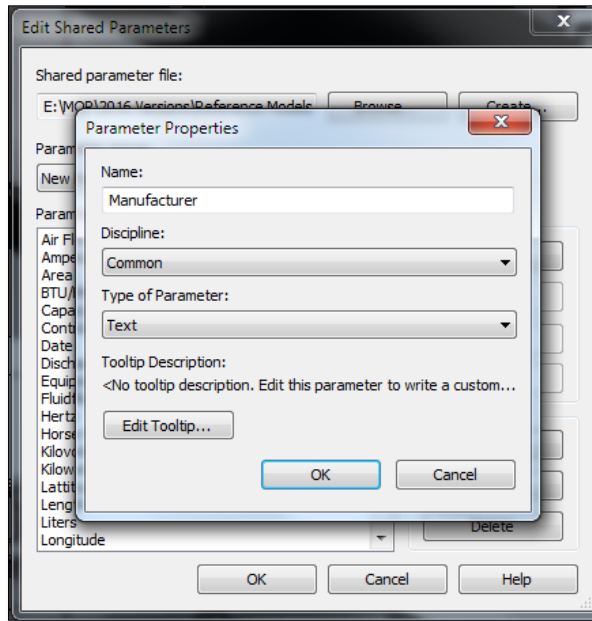
Figure 23: Window to Create Parameters
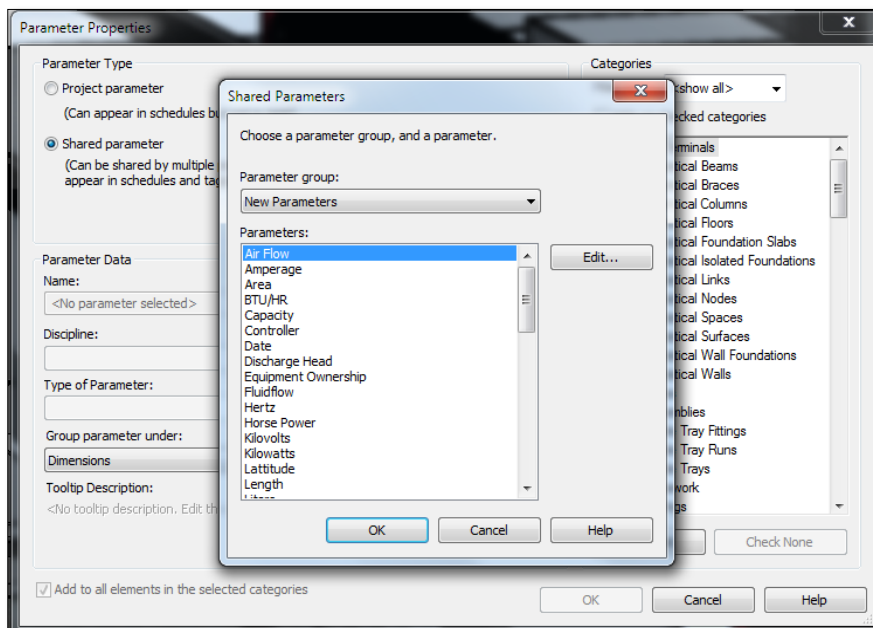
Figure 24: Window to Assign Parameters

The type option was used to assign the attributes. The parameters could either be added based on type or instance, this means that the parameters' entered data could be unique for each type of object, so all air conditioners would have the same field, or by instance, so each individual object would be able to have different field values. It is because of this step of

attaching the parameters, which made it so important to add or represent objects in the correct categories. The parameters were not attached to each individual object but instead all objects in the categories selected for the parameter would then contain the field. Throughout the refinement, the team added 109 objects from the desired asset list and created over 100 unique parameters to contain the data of the assets.

3.3 Viewing Capabilities

The model is not useful if the end user is not able to view the information needed in a productive way. After refining the model with the desired information, all the needed assets for facility management and their corresponding parameters, the information was exported from Revit software to Navisworks software. Then, in Navisworks, all the capabilities of the program are able to be used to manipulate and view the model. There are features to walk through the model when the user is in first person and objects and features of the model can be viewed first hand. When an object of the building is selected the data for that particular object appears in a pop-out box. This is where the parameters and their values are located for that particular object. When trying to view the parameters it was found that in order to see all the information corresponding to an object, additional steps still needed to be taken. When the file is first opened, only the data that is previously in Navisworks is seen. To view the parameters transferred from Revit, the user must right click on the object and select "Set Selection Resolution to First Object". Then all the parameters may be viewed in the tab labeled "Element" as seen in Figure 25 below.

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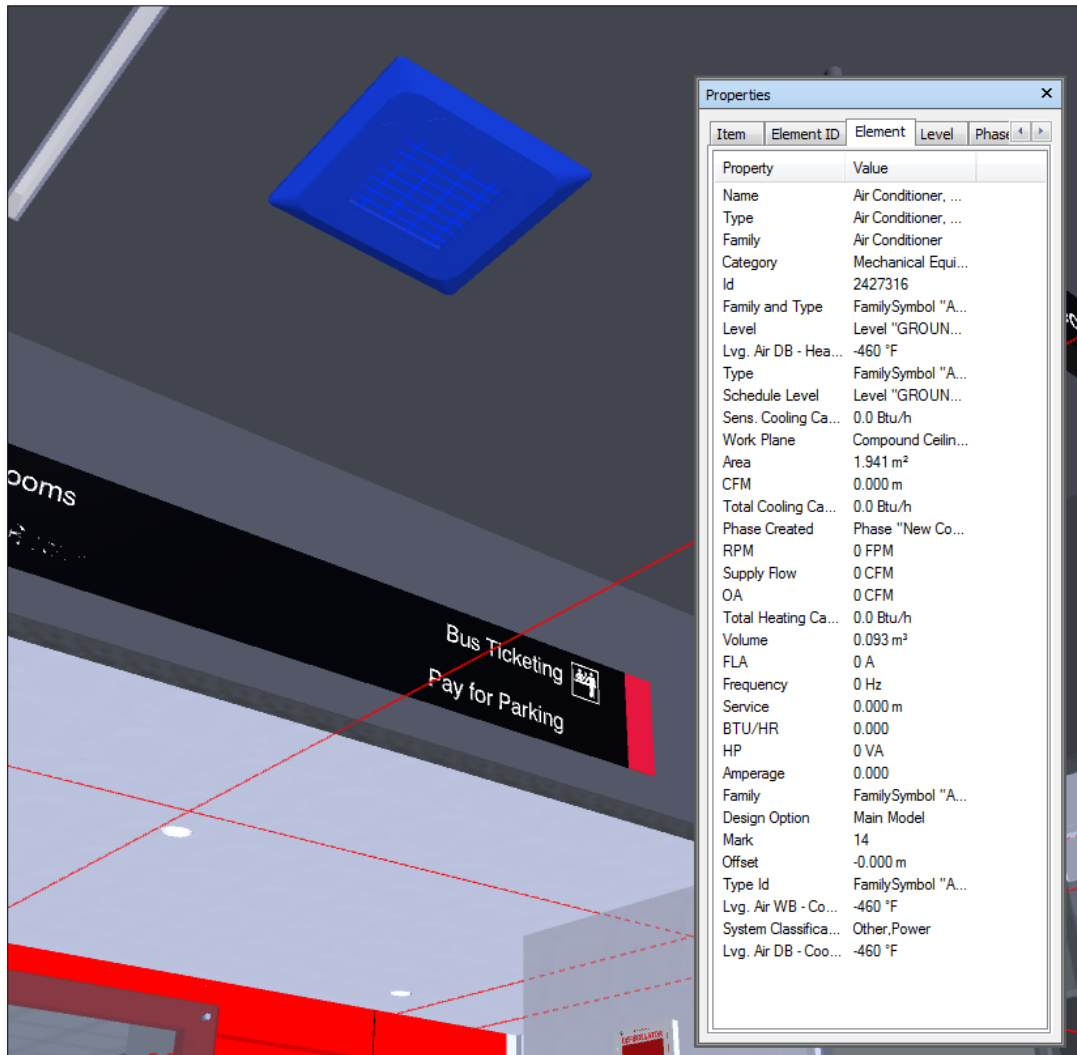
Figure 25: Viewing Object Parameters in Navisworks

Navisworks is fairly user friendly and does not need significant training to use the simple viewing capabilities. Currently, Massport is training a handful of project managers to better understand the uses and applications of Navisworks. If Navisworks models are employed for facility management operations then the personnel will be able to conduct an interactive walkthrough through the model and view various objects. This allows the user to gain an understanding of the location of the actual object, versus just have a serial number in a table representing that particular object. Once the user locates the object, all the data added into the Revit model may be easily accessed and viewed by simply pointing and clicking directly on the object. If it is preferable, the user may even add more information or notes about the object in question that will continue to be attached to the object in the Navisworks file.

4.0 Improved Process

The work developed in chapter 3 is intended to produce a model that can be used by Facility Management; however, this was done after the design and construction BIM models were created. Since most of the design and construction was done without the involvement of the facility management team, the asset information need by FM was not included. This cause an extra step of tagging and recording the data for the assets of the building, which is redundant and time consuming since it is information that was much more accessible when the BIM models were being created. Also, generally the information collected from the tagging is not always incorporated into the models, so the models are never completed to the extent which facility management needs. The solution proposed is an established template that may be given to the different contractors or designers for a project.

4.1 Handover Process

To create the BIM model template, the team used the model that was refined, mentioned above. This was the architectural model that had the structural, MEP, and bulletin models linked. This model now contained all the objects loaded and the parameters created and attached. Once saving the file as the template name, the team deleted all field values and items in the file so the result was once again a blank file ready to be used for modeling. When the file was blank, it still contained all the parameters the team had previously added. It also had the parameters connected to the appropriate categories for objects defined in the refinement of the previous model. The team saved the file not as a project but as a template so when a new project is opened, the user may select this template to work from.

The purpose of creating a template is to assure that when the model is being created, all the desired parameters are already contained in the file. Therefore, this allows the user to be prompted with the correct attributes to complete when creating the model early on. So when an object is added to the model when the as-built model is being created, the field to enter in the specific data is there for use. The user does need to consider which attributes of the objects would be helpful to the owner nor does he or she have to make the parameter his or herself because the template contains all the necessary fields. This eliminates the need to obtain the data

after the fact because the information for each object is added into the model as the actual items are purchased and installed by the contractor.

However, problems may arise with miscommunications or uncooperative parties. To proactively prevent this, the required use of the template could be incorporated into the contract created between Massport and the design contractor. Currently, the contracts require certain end products, such as models in Revit, so the more complete models made from the given templates is under the current workload requirements. If any parameter or object is not included in the template for the particular project ahead of time then it may be added in manually once the model is received from the contractor, using the steps mentioned in section 3.1 above. Although the template may not contain all necessary attributes and assets, it eliminates the need to tag and record all the objects of a building. By providing the initial template, only a handful of newly identified unique or overlooked assets will have to be recorded retroactively versus the entire array of assets as is the process currently being done.

4.2 Facility Management Operations

While considering solutions for the overarching problem of interoperability between software, integration research was made to look into other possible options. The team investigated various software and processes to consider for facility management use. Each option was further researched and numerous benefits and limitations were determined. The below chart displays the some possible integration tools and their evaluations.

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Table 1: Integration Software Evaluation

Program/Approach	Benefits	Limitations
Revit	- Editable - Various views	Require significant training
PDFs	- Simple - Minimum required training - Coordinated Steps	- No 3D model - Paper
Maximo	Currently used	Not connected to model
EcoDomus	Model viewing	Requires training, not as common knowledge
BIM 360	- Autodesk Product - Handheld App - Not limited by size of file (The Cloud)	Security (cloud application)
YouBIM	- Handheld App - Extensive capabilities - Large compatibility	New Product
Assemble	Extensive capabilities	Expensive
Navisworks	- User-Friendly - Current training in progress	Not backwards compatible

The driving factors in assessing the benefits of the alternative approach were the practicality, learning curve, and interoperability of each option. Cost should be considered but it was not included in this assessment since software is quoted on a project-based system.

Massport is currently using Autodesk Navisworks and IBM Maximo for asset viewing and management. Although there is much value in the 3-dimensional aspects of BIM software, the current use of PDF's for asset location is the most widely used amongst the Facilities Management staff. An additional software, EcoDomus, was researched for its ability to automatically to bridge the gap between BIM and FM software.

The first program reviewed was Navisworks. As noted in section 3.2.1.3, Navisworks is used to optimize scheduling through 4D and 5D modeling, detect clashes and create an environment for communication between different trades. The ability to import files from an array of diverse software enhances the use of Navisworks. It also gives options to different trades work to use their preferred software; therefore, this platform lends itself to an easier adaptation and interoperability. Since its main use is for visualization, most of its capabilities can be

understood with simple training. This makes this software easy to learn. In addition, its capabilities to collect different types of files, show clashes, 4D and 5D simulations, and its user-friendliness make this software very practical. The software's current limitation is its inability to edit model information for wider use with FM software.

IBM Maximo is currently also working towards bridging the gap between BIM and FM software. An advantage of 3D models is the visual advantage for planning purposes. This advantage allows the facility management staff to prepare the proper equipment and see the location of an asset without needing to know how to get around a facility. An extension for Maximo was released in January 2016 and focuses on the 3D model viewing capabilities of BIM software. The model would be linked from BIM model software and can be used to look around a model for assets and create work orders. The extension now allows Maximo to offer 3D asset viewing capabilities. Although this enhances the possible integration of BIM and FM, it does not address its inability to update asset information in the 3D models.

The Portable Document Format (PDF) is the most widely used digital format for 2D floor plans and building information. This format allows large sheets of physical documents to be converted into a digital format that can be more accessible and searchable. This allows facility management staff to locate assets, but does not allow any information to be updated in the PDF files. Bluebeam technology is also enhancing the capabilities of PDF's. Bluebeam allows for legends, batch markup summary, and document tab preview.

Although Massport is not currently using EcoDomus, it was researched as a possible solution for bringing BIM and FM software into one software. This program has the capability of showing 3D models from a variety of software programs; these can be but are not limited to Navisworks files, Revit models, and Tekla files. As previously mentioned in section 2.3.3.1, EcoDomus has the ability to integrate BIM model and FM software into one interface. This allows work orders to be made while also being able to look up an asset on a 3D model and find any details from that model about the asset. EcoDomus does well in allowing information to be edited and updated in both FM software and BIM software. The current limitation is the creation of new assets and the lack of standards for receiving information in anything other than COBie.

4.2.1 Experimental Solution to Software Data Integration

The current Autodesk Revit software does not have a direct connection with the Maximo FM software. This has led to a missing link between the information created in Revit models and the information that is constantly being updated for the asset management. The team researched and worked on Revit to try and find a connection with the information-rich models and Maximo's asset database.

As aforementioned, Revit has a capability to create schedules of the assets or objects in the model. From these schedules, any parameters previously added could be extracted into a table. This table can then be exported from Revit as an excel spreadsheet.

Maximo's asset management systems also has an export feature. This export feature has several options but the team focused on the excel spreadsheet feature. Using the excel file from Maximo, there are formats for the way Maximo can read information and these can be seen in the exported excel spreadsheet. This then lends itself to some manipulation to bridge the gap between the information from Maximo and the Revit models. When the excel file is updated, it can be saved as a CSV file for use in either Maximo or Revit. Although it is currently not an automatic software to software information exchange, this does allow for information to be exported from each program and for manipulations to be made to update each system.

For this possibility, the collaboration of Maximo and Revit becomes more appealing for the successful integration of BIM and FM software. This kind of manipulation however, takes training, as it is not easy to understand. Understanding the way Maximo and Revit read the spreadsheet files becomes the emphasis of training.

Using a template for the information format can increase how efficient and user-friendly this process can become. This template, unlike the one proposed for the handover process, would be used for the excel file to update the asset information between software. This helps take away any extensive training that would need to be done for Revit, Maximo, or any other software package as it shifts the technical knowledge from those packages and into a simpler Excel spreadsheet.

5.0 Structural Analysis

The study was extended to explore extensions for BIM model interoperability for structural design purposes. A structural review of the existing Framingham garage was conducted. To do this, both hand calculations and software-aided analyses were conducted. The pre-stressed double tees of the framing system for the garage were analyzed to assess the appropriateness of the sizing and materials for the designated loads. The steel members of the garage's internal lobby area were also investigated to assure the capacities were sufficient. Once completing the calculations by hand for the lobby area, the team created and analyzed the model of the members using the software program, Robot Structural Analysis professional. The information regarding the steps of these calculations and processes are further detailed in the following sections.

5.1 Steel Frame Analysis

The team started the hand calculation by investigating the steel framing of the lobby. Using the structural as-built models in Revit provided by Massport, the sizing and materials of components were gathered. The section of the lobby that was chosen was a bay which was the largest in the system that framed the boundaries of the lobby area. The bay itself is 37 feet 10 inches by 26 and a half feet. And it is supported by four W12x65 steel columns at the corners. The beams which spanned between the columns were found to be W12x40 and the interior most beams of the system are W12x19. The team also used the structural pdf drawing documents given by Massport that were created during construction. These documents contain the specifications of materials, capacities of components and loading conditions.

The appropriate beams for the scheme was determined from calculations for both the plastic bending capacity and serviceability. The plastic bending capacity deals with the strength of the member. At a certain point, when both the section of the member in tension and in compression completely yield, a plastic hinge is formed. This hinge is located at the maximum moment along the member in the fully plastic cross section. With the creation of this third hinge in addition to the already existing two supporting hinges, the member will fail. Therefore, the size and type of the member necessary to prevent this failure was calculated. The calculations

performed determined the uniform load, the plastic capacity and then the plastic section modulus. Since this was a review of the capacity of the existing members, the team was able to include the self-weight of the beams in the beginning calculations. The structural documents revealed that the members supported the dead load of their own weight in addition to the designated 100 pounds per square foot for the lobby area. If the calculations provide a value that meets the requirements for the selected member, then that said member is appropriate for the strength portion to support the system.

The second standard that was investigated to determine the proper beams was the serviceability. This feature is related to the deflection of the members. The members were tested to assure they can withstand the total load for the area. For this project 50% of the live loads were used for the calculations and they were compared to the equations L/360 or 1 inch and L/240 for the floor live load deflection and the total deflection. This check of serviceability assures that the cross section of the member is able to withstand the tolerance of deflection for the span.

Through the calculations using the provided pdf documents and the values in the AISC Specifications, the team was able to conclude that the members were sufficient for their purpose (AISC, 2013). Both sized members, the W12x19 and W12x40, were appropriate for strength capacity and deflection resistance. Appendix E contains the in depth calculations and computational processes.

5.2 Double Tee Analysis

The following component of the structure that was analyzed was the double tee beams. These are pre-stressed concrete components that span between the columns of the garage. The double tees span an average distance of 60 feet and are typically sized as seen in the documents in Appendix D. Based on the material properties, geometry, loading and support of the members, the team was able to calculate and distinguish the effectiveness. The team also used the spreadsheet created by a previous MQP team comprised of Jose A. Cueva, Jean Pierre Miralda, and Saadet Nur Yilmaz (Miralda, Cueva, & Yilmaz, 2015).

The creation of a pre-stressed member includes the pre-tensioning of the steel fibers which are set in the concrete. These 7-wire strands are located below the center of gravity of the member, so when the tensile force holding the strands is released, the bottom of the member

compresses and the top undergoes tensile forces. This causes the member to camber and gain a visible deflection upwards. This is done so that when the additional loading is added, the member's top portion will go into compression from tension and the compression on the bottom portion will decrease. The beam will bend back to a more horizontal direction and the affect is that the member has a far larger strength capacity than general concrete (J. Rosewitz, Personal Communication).

To begin, the structural documents were searched for dimensions, loading, and properties that would be necessary for the calculations. The area designated to represent the structure's double tees was chosen as a section of the top level were the framing was assumed to be flat and the loading was specified. The loading capacity was checked for three cases of the structure. The areas included the parking with 40 psf of live loads, the terminal with 100 psf of live loads and the roof with 20 psf of live loads. Due to the creation and logistics of pre-stressed concrete the team had to check the capacity of the beam at various assumed stages in the usage of the member. These stages are the capacity at release on both the end region and midspan region, during formation of the member, and then also the capacity at the midspan while the member is in service.

Using the PCI Design Handbook, the team assumed the diameter of the strand of steel in the member was 0.6 inches and the calculations began with 8 strands in the double tee. The team had to enter the proper geometry, properties and loading conditions in to the designated equations to determine various components to contribute to the final evaluation of capacity. These parts were the creep of the concrete, the elastic shortening, the shrinkage of the concrete and the relaxation of the tendons (Miralda, Cueva, & Yilmaz, 2015).

Once the main sections were each calculated through the spreadsheet, the stresses on the three designated conditions were found. To do this the individual stresses in different areas, such as the top and bottom of the beams, were calculated and then combined to find the total stress on the member during that condition. Based on guidelines and limits found in the PCI Handbook, the stresses were designated as within the limits or not for effectiveness. When it was found that the member did not fall within the limits or if the results showed the beam would be cracked, inputs such as the number of strands and the eccentricity were adjusted to represent stronger members.

As a result of the calculations it was found that with the largest loading, which would correspond to the terminal section, the double tees need 20 strands so that it will meet the three capacities for stress. All the calculations which relate to the work described in this section may be found in Appendix F.

5.3 Robot Structural Analysis

The final component of the structural analysis for the project was to incorporate the chosen steel framed portion of the lobby into the software program. From the BIM models provided, the team was able to recreate the various members and columns for the designated bay. In a separate Robot Structural Analysis file the bay was modeled to assure it was the only component being analyzed and the geometry and connections were correct. The selected section drawn in Robot Structural Analysis can be viewed below in Figure 26.
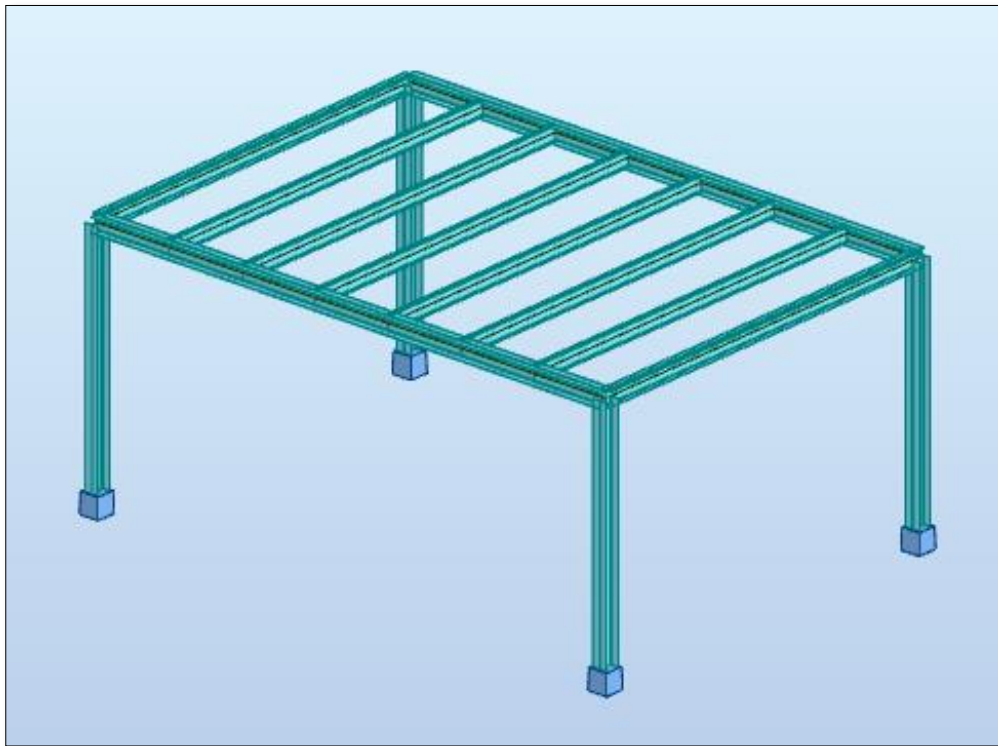
Figure 26: Lobby Framing Drawn in Robot

After designating the proper sizes and layout of the specified columns, beams and girders, the loads had to be identified. The team found the factored loads that acted as distributed loads on each beam from the structural documents and dimensions. By first identifying the type

of loading, the team was then able to assign a value to the loading conditions and apply them to the corresponding members. The labeled distributed loads applied to each beam can be seen in the figure below (Figure 27).
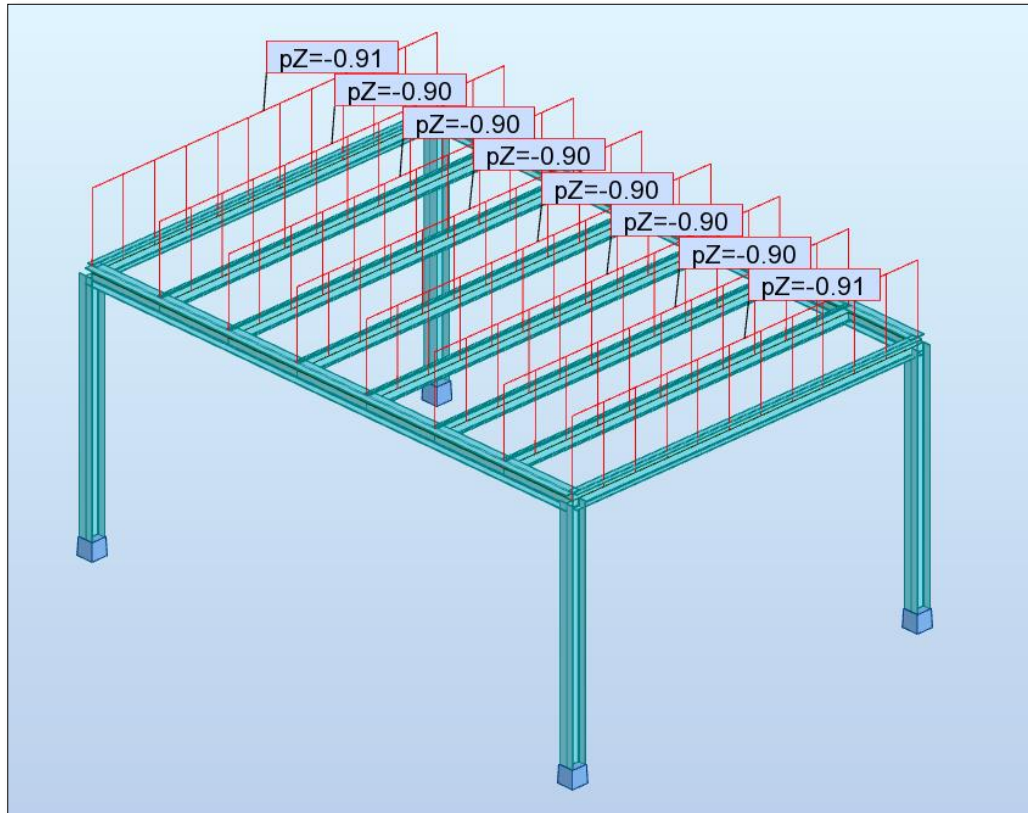
The final step of the analysis in the software was to simulate the calculations to obtain the information about the members and load cases. The results from the calculations provided the team with various data, such as moments, deflections and axial forces on the structure. These results were comparable to the values obtained through the hand calculations.

While conducting this portion of the structural analysis, the following issues were observed. BIM model configuration could not be exported successfully to Robot Structural Analysis because the anylitical model did not meet all conditions for proper export. As a result the geometry of the frame was recreated within Robot itself. This also proved difficult because each node had to be added by specifying the x, y and z coordinates for each. The graphic user interface of this software is not very user friendly in the sense of creating the model. Other than that, there are a few beneficial features such as adding a dead load to represent the self-weight of

each member on the system was very useful. Also, the results which the program collects are very extensive and, when understood and used properly, can be very applicable.

6.0 Conclusions and Recommendations

The team focused on improving the effectiveness and usability of BIM technology for Facilities Management. This chapter will state the conclusions drawn from the project and recommendations the team has for future BIM Facilities Management work. This will include the improvements for the handover process for better resource attainment for facility management and the investigation on practices to improve facility management for building operations.

6.1 Improved Handover Process

Through the investigation of current processes being used by Massport for their projects, the team learned that the facilities management team, which would find the BIM software most beneficial, is not involved early in the construction process. This leads to a retroactive approach for the facilities management team. Any information that is needed for the assets must be located through the many files of warranties and asset–specific information. Without early engagement from the FM team, the models become more difficult to use and less practical as the required information has not been connected to the assets in the models. The new handover process guidelines, which can be found in Appendix C, created for this project can be seen in the following sections below and are the recommendations for improving the handover process and BIM usage in facilities management.

6.1.2 Contract with Template

The team reviewed the workflow used for inputting information and concluded that a systematic approach would be most appropriate to improve the handover process. The current workflow does not require the facility management team to work early on in the design or construction process. Having the FM team included early in the process would allow the team to create or customize model templates for the project. This process would give the data integration team an opportunity to focus on creating or editing the parameters desired in the model for the facilities management use. The model template or template file would be contractually used throughout the design and construction phase to collect the data during installation of assets versus retroactively. Doing this would in effect lead to a BIM model that is not only accurate but is also rich in valuable and up-to-date information. This template-based system should

theoretically work for decreasing the amount of time that is used in ensuring that desired parameters are in the models by populating models early on with information attached to the objects.

6.2 Improved Facility Management Operations

The current software programs used for facility management and BIM may require an extensive training program. For this reason, many FM users do not become familiar with the software or technology that is presented throughout the different BIM platforms. Even when information can become very impactful and powerful, the complexity of programs like Autodesk Revit can discourage FM employees from accessing information in the BIM models. Another important aspect to consider when investigating FM software and processes is the cost of the platform. When investigating a possible integration option for the use in facility management operations, the team conducted a pros and con analysis on various items, including factors such as practically, cost and benefits.

6.2.1 Recommended Integration Software and Further Research

From the integration research and the final presentation at Massport, it became evident that the user-friendliness of the software is one of the most important driving forces in the adaptability of the software. The current use of PDF files for 2D floor plans lends itself to the traditional format of searching for asset location and information. This information will tend to become outdated overtime, and without a way to edit the information on PDF files, the maintenance of the assets will become increasingly more difficult. It is recommended that 3D modeling software be used to create as-built models and that these are maintained to ensure the information is accurate. By keeping the 3D models accurate, 2D floor plans can be created with the most updated information for facility management staff to use. These are possible solutions while the technology improves. Once there is software that can be user-friendly for any staff member to confidently use and find value in, there can be a transition towards 3D BIM and FM software use. This transition can also be sped up with investment in training that focuses equally on the software needed to learn and the value that each staff member can receive from learning and using the new software-based process.

6.3 Structural Analysis

The additional component incorporated in the work of this project was the structural analysis. A structural review of various systems throughout the garage was conducted. Through hand calculations, the effectiveness of the steel framing for the lobby area and the double tees of the structure evaluated. The Robot Structural Analysis software was used to investigate the interoperability between it and Revit, and also to confirm the results of the review for the lobby's steel framing. Through the three methods, the differing sections and components were all determined to be designed effectively for the loadings and the purposes designated.

6.3.1 Recommendations for Structural Analysis Procedures

For future analyses of structural systems of this nature, further research into the interoperability capabilities of Robot Structural Analysis or a different software program is recommended. In this study the use of Robot in this way was efficient or effective. However, with further research and training of the capabilities and uses, the program may prove to be beneficial in the future. It is also suggested to investigate different software packages that may have more comprehensive applications and BIM interoperability features.

6.4 General Recommendations

Throughout the project, there were some inherent obstacles in working with the files for the Framingham garage because there is no backwards compatibility for Autodesk Revit. The first step was to update all the files to Revit 2016 files. It is recommended that files be kept with the most up-to-date software packages as any older versions may become obsolete. Any work done by subcontractors, project managers, designers, and other members of a project must be usable in a specified open format.

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Appendix

Appendix A: E-Files

Throughout the course of this project the team used and created numerous E-files. The list below describes the files submitted with the report to help further clarify any components of the work.

Zipped File Folder- Final FILES

- Revit Files
    - Revit_Files -This internal folder contains all the Revit files that were revised for the project.
    - ARCHITECTURAL_LEXF_TERMINAL_CENTRAL_Bulletin18-GOLD-TEMPLATE.rte –This the template created by the team to improve the attainment of data through the handover process.
- Navisworks Files –These are the files which were created to view the models in Navisworks.
    - ARCHITECTURAL_LEXF_TERMINAL_CENTRAL_Bulletin18-GOLD.nwc
    - ARCHITECTURAL_LEXF_TERMINAL_CENTRAL_Bulletin18-GOLD.nwd
- Excel of Attributes –This file is the original excel file containing the parameters and assets provided by Massport that was used to revise the models.
    - Asset Class with Attributes
- Excel for Double Tees –This file contains the calculations for the double tee structural review.
    - Analysis of Double Tees
- Robot Structural files – This file includes the work and analysis made with the Robot Structural Analysis software.

Appendix B: Sample of Asset Attribute Spreadsheet

| ID	Code	Description	Attr 1	Attr 2	Attr 3	Attr 4
1000	AC	AIR CONDITIONER	10 AIR FLOW	AMPERAGE	BTU/HR	EQUIPMENT OWNERSHIP
1014	ACROOF	AIR CONDITIONER, PACKAGE ROOF TOP AIR CONDITIONER	28 AIR FLOW	AMPERAGE	BTU/HR	EQUIPMENT OWNERSHIP
2000	ACS	ACCESS CONTROL SYSTEM	2 EQUIPMENT OWNERSHIP	TYPE		
	ACSS	ACCESS CONTROL SYSTEM				
1001	ACSSACC	AIR CONDITIONER SPLIT SYSTEM	11 EQUIPMENT OWNERSHIP	MOTOR MANUFACTURER	MOTOR RPM	MOTOR AMPERAGE
1005	ACSSACC	AIR CONDITIONER, SPLIT SYSTEM, AIR COOLED CONDENSER	23 AIR FLOW	AMPERAGE	BTU/HR	EQUIPMENT OWNERSHIP
1003	ACSSFCU	AIR CONDITIONER, SPLIT SYSTEM, FAN COIL UNIT	21 AIR FLOW	AMPERAGE	BTU/HR	EQUIPMENT OWNERSHIP
1030	AD	AIR DRYER	12 HORSE POWER	VOLTAGE	PHASE	HERTZ
1032	ADREFG	AIR DRYER, REFRIGERANT AIR DRYER	7 AIR FLOW	EQUIPMENT OWNERSHIP	MODEL NUMBER	REFRIGERANT TYPE
1040	AHU	AIR HANDLER	17 AIR FLOW	AMPERAGE	BTU/HR	EQUIPMENT OWNERSHIP
1043	AHUHV	AIR HANDLER, HEAT VENT	3 PHASE	HERTZ	VAC	
1044	AHUHVAC	AIR HANDLER, HEATING VENTILATION AND AIR CONDITIONING HVAC	4 AMPERAGE	VOLTAGE	PHASE	HERTZ
1042	AHUMUA	AIR HANDLER, MAKE UP AIR	10 AIR FLOW	AMPERAGE	BTU/HR	EQUIPMENT OWNERSHIP
1041	AHUROOF	AIR HANDLER, ROOF TOP UNIT	3 VOLTAGE	PHASE	HERTZ	
2003	BFP	BACK FLOW PREVENTER	2 EQUIPMENT OWNERSHIP	MODEL NUMBER		
1061	BLR	BOILER	6 AMPERAGE	HORSE POWER	VOLTAGE	PHASE
2005	BUSWAYLV	BUSWAY, LOW VOLTAGE	5 AMPERAGE	EQUIPMENT OWNERSHIP	MODEL NUMBER	VOLTAGE
2032	CABPW	CABINET, POTABLE WATER	6 AMPERAGE	EQUIPMENT OWNERSHIP	MODEL NUMBER	VOLTAGE
2050	CHILL	CHILLER	7 REFRIGERANT TYPE	VOLTAGE	PHASE	
2051	CHILLREF	CHILLER, REFRIGERANT	1 EQUIPMENT OWNERSHIP			
1060	CMPSR	COMPRESSOR	6 AMPERAGE	HORSE POWER	VOLTAGE	PHASE
2091	CMPSRAIR	COMPRESSOR, AIR	2 VOLTAGE	PHASE	HERTZ	
1062	CMPSRDUP	COMPRESSOR, DUPLEX AIR	26 AMPERAGE	EQUIPMENT OWNERSHIP	HORSE POWER	MODEL NUMBER
1064	COILCOOL	COIL, DIRECT EXPANSION COOLING	4 AIR FLOW	WEIGHT	AREA	VELOCITY
1052	COILGLYCOL	COIL, GLYCOL	5 BTU/HR	TEMP	FLUIDFLOW	VALVE MODELNUM
1053	COILHOT	COIL, HOT WATER	11 AIR FLOW	BTU/HR	EQUIPMENT OWNERSHIP	MODEL NUMBER
1083	DAMPERATCOUT	DAMPER, A/C OUTDOOR AIR	3 AIR FLOW	VELOCITY	PD (H2O)	
2055	DEFIB	DEFIBULATOR	1 EQUIPMENT OWNERSHIP			
2966	DETECTORGAS	DETECTOR, GAS	4 AMPERAGE	VOLTAGE	HERTZ	DC
2007	DF	DRINKING FOUNTAIN	2 EQUIPMENT OWNERSHIP	MODEL NUMBER		
2006	DOORMAN	DOOR, MANUAL	1 MASSPORT ID			
104	DOOROVER	DOOR, OVERHEAD	6 EQUIPMENT OWNERSHIP	HORSE POWER	MODEL NUMBER	VOLTAGE
103	DOOROVHCOIL	DOOR, OVERHEAD COILING	8 AMPERAGE	EQUIPMENT OWNERSHIP	HORSE POWER	MODEL NUMBER
102	DOORSLID	DOOR, AUTOMATIC SLIDING	2 EQUIPMENT OWNERSHIP	MASSPORT ID		
2008	EWES	EYEWASH / SAFETY SHOWER	2 MODEL NUMBER	VOLTAGE		
2052	FALM	FIRE ALARM	1 EQUIPMENT OWNERSHIP			
2054	FALMAP	FIRE ALARM, ANNUNCIATOR PANEL	1 EQUIPMENT OWNERSHIP			
2053	FALMCP	FIRE ALARM, CONTROL PANEL	1 EQUIPMENT OWNERSHIP			
121	FANEXHAUST	FAN, INLINE EXHAUST	18 AIR FLOW	EQUIPMENT OWNERSHIP	HORSE POWER	MODEL NUMBER
122	FANRETURN	FAN, RETURN AIR	9 AIR FLOW	HORSE POWER	VOLTAGE	PHASE
124	FANROOF	FAN, ROOF TOP EXHAUST	5 AIR FLOW	RPM	DATE	DESIGN SP
125	FANSUPPLY	FAN, SUPPLY AIR	9 AIR FLOW	HORSE POWER	WEIGHT	HERTZ
2155	FLTAIRCMP	FILTER, AIR COMPONENTS	4 AIR FLOW	WEIGHT	AREA	VELOCITY
137	GENEMER	GENERATOR, EMERGENCY	14 ALTERNATOR MODELNUM	ALTERNATOR MANUF	BATTERY CHARGER MODELNUM	BATTERY CHARGER MANUF
136	GENEMERDIESEL	GENERATOR, EMERGENCY / DIESEL	6 EQUIPMENT OWNERSHIP	MODEL NUMBER	VOLTAGE	PHASE
150	GLYCOLMAKEUP	GLYCOL, MAKEUP SYSTEM	13 AMPERAGE	EQUIPMENT OWNERSHIP	HORSE POWER	MODEL NUMBER
171	HEATERAIR	HEATER, AIR CURTAIN	6 AIR FLOW	BTU/HR	EQUIPMENT OWNERSHIP	HORSE POWER
172	HEATERCAB	HEATER, CABINET UNIT	12 AIR FLOW	BTU/HR	HORSE POWER	VOLTAGE
173	HEATERELUNIT	HEATER, ELECTRIC UNIT	8 AIR FLOW	BTU/HR	EQUIPMENT OWNERSHIP	HORSE POWER
2194	HEATERAF	HEATER, FORCED AIR FUEL	2 AIR FLOW	MBH		

Appendix C: Guidelines on How to Add Parameters, Attributes, Schedules, and Exporting Data into Excel
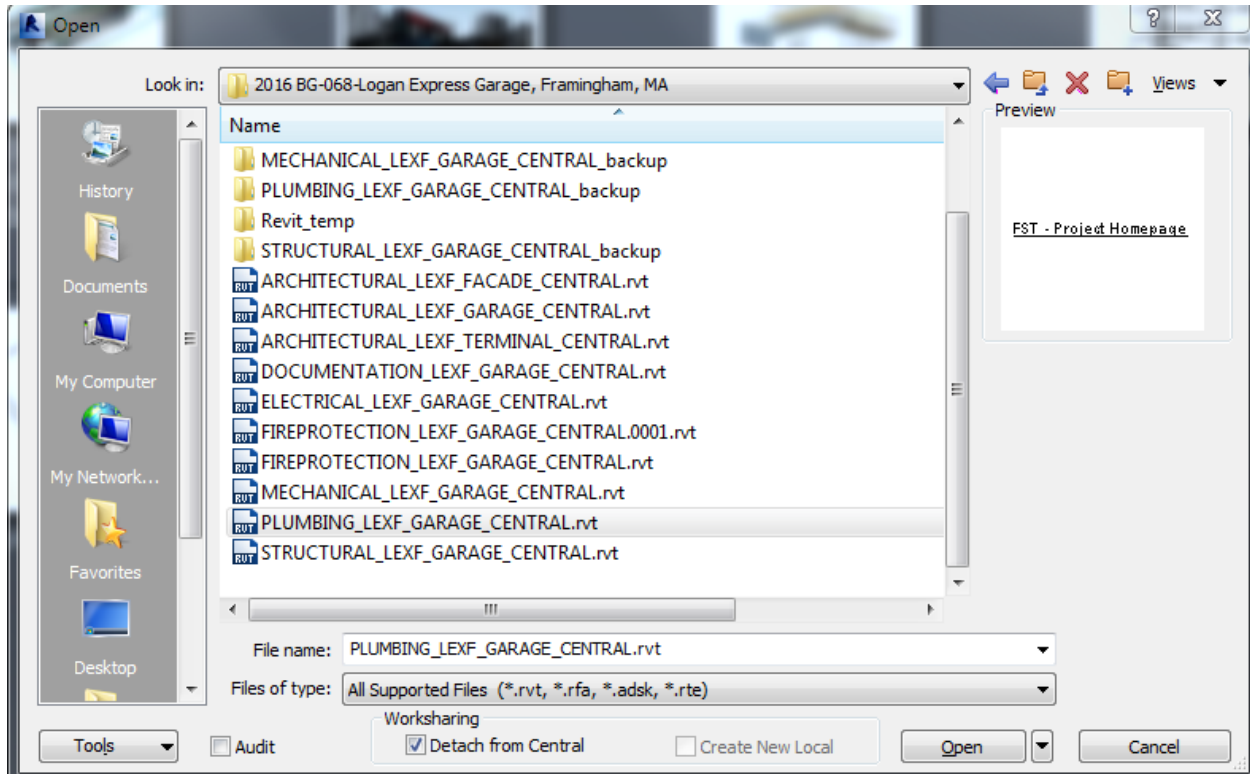
Depending on the editing rights the user may have, the file may not be edited or used for anything than the visual content. To allow edits to be made and saved from a new user, the file must be "detach from central."
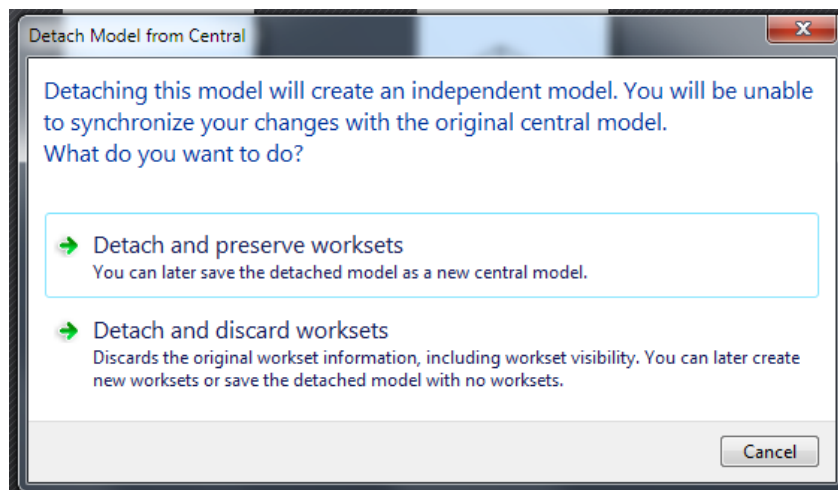
After clicking "open" for the selected file, Revit will ask if you would like to preserve or detach the worksheets in the document. Using the "preserve worksheet" option allows previous worksets to be used and a new central model to be created.
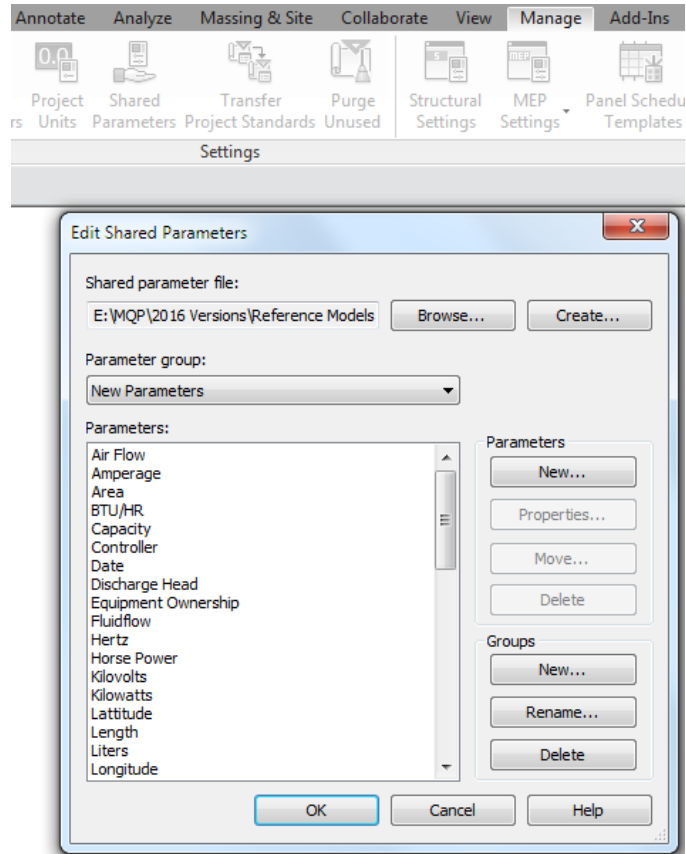
To begin adding the parameters, go to the Manage ribbon and choose the "Shared Parameters" option. The screen that opens after clicking is seen above. Before you can start creating any parameters that you wish to have for your assets, you will need to create a text file using the "create" option on the right of the screen. This will allow you to access your parameter list and use it for any other project.
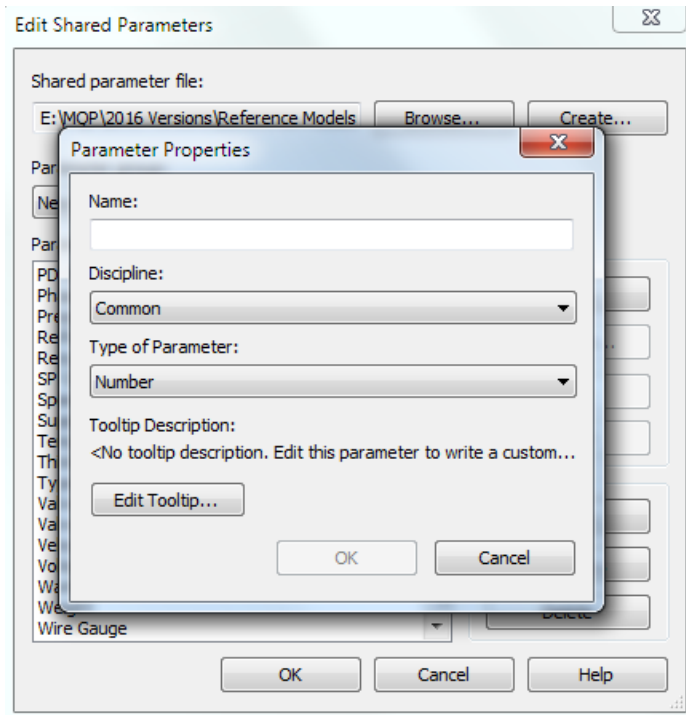
To add a parameter, use the "new" option under parameters; using text as the type of parameter will allow flexibility with the values as they will be taken as simple text.
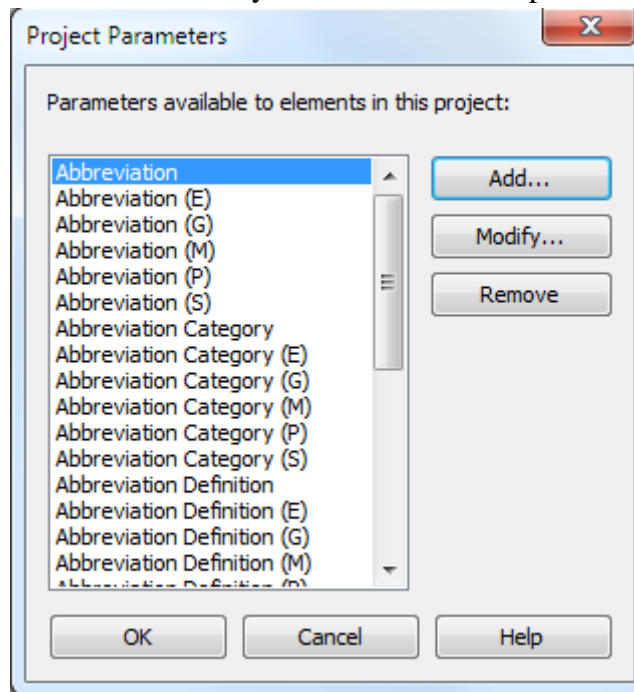
Once the parameters have been created, you may close the "edit shared parameters" window and click on the "Project Parameters" option. This will allow you to add the parameters you just created to any asset types you wish.
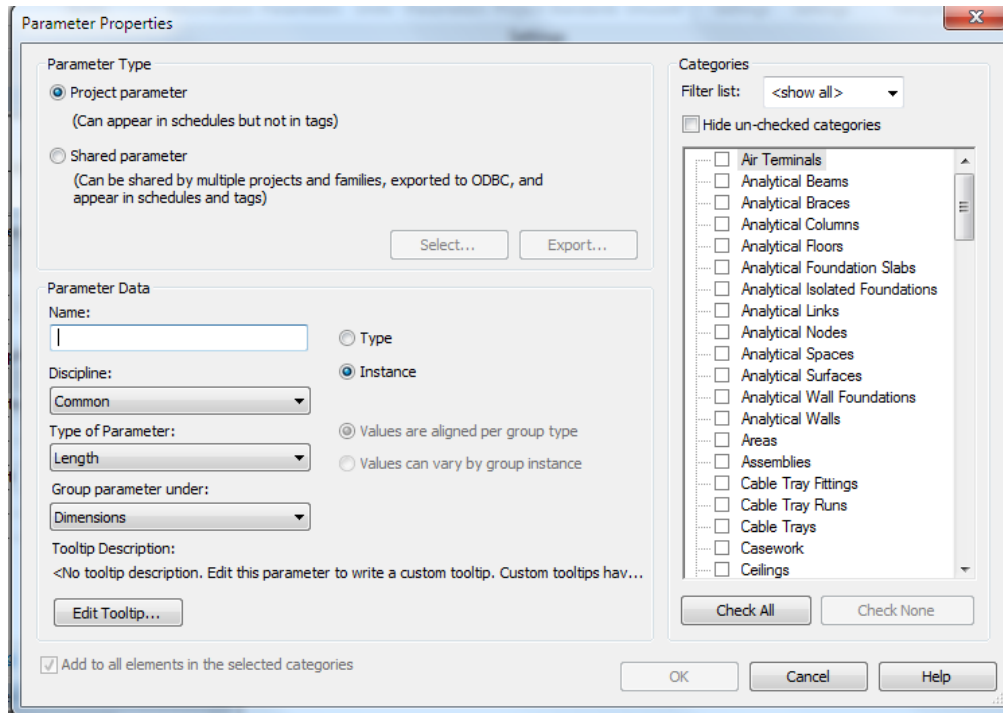
To insert the parameters you just created, click on the radio button with "Shared Parameters." From here you will be able to add all of the parameters and choose the asset categories that will need the parameter. Clicking the type option is recommended for a parameter that will hold the same value across all the assets designated with that parameter; if you would like to vary the values in the parameters across different assets, use the instance option.
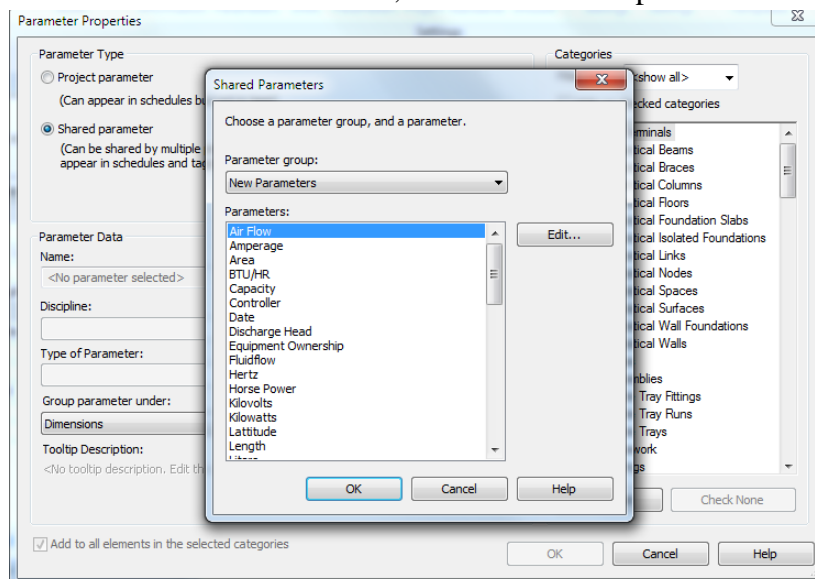
One of the most useful asset organization tools is creating schedules with the assets and the parameters wanted. To do this, click on the analyze ribbon and then on the

"Schedule/Quantities" option. This will open a window from which you may create a new schedule with the name you wish.
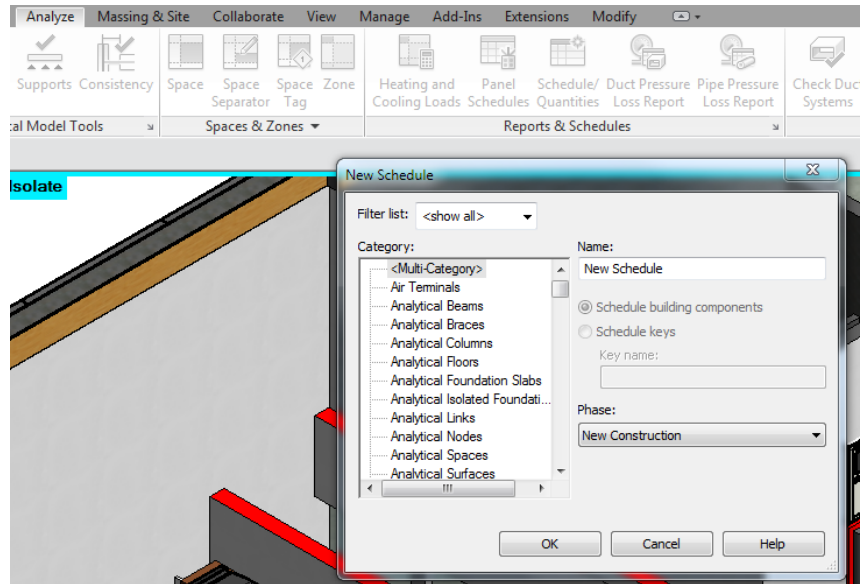
After creating a new schedule name, add the fields that you wish to have shown. These end up being your parameters and may include Name, Family and Type, and Quantity as some of the basic description information. You may add as many parameters as you wish to extract more information.
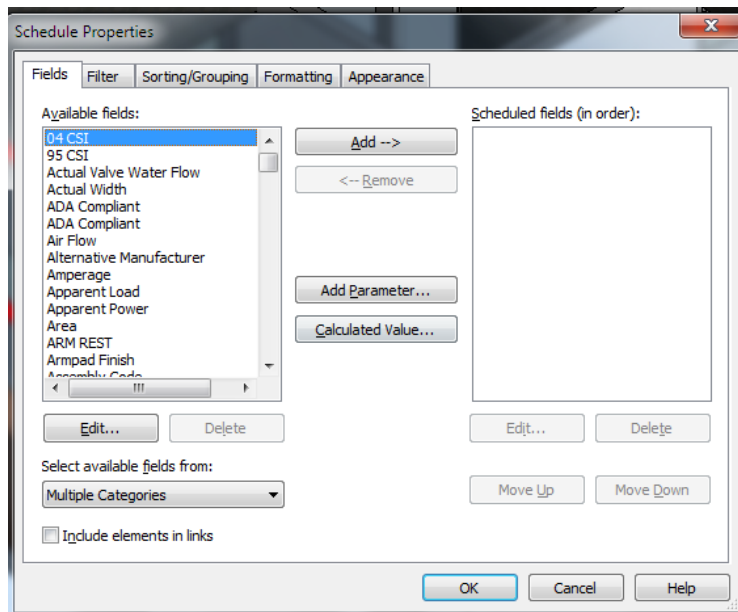
Properties

⊞	Schedule

Schedule: Multi-Category ▼   ⊞ Edit Type

Graphics ⌃
Visibility/Graphics ...	Edit...

Identity Data ⌃
View Template	Schedule - Ab
View Name	Multi-Category Sch...
Dependency	Independent

Phasing ⌃
Phase Filter	Show All
Phase	New Construction

Other ⌃
Fields	Edit...
Filter	Edit...
Sorting/Grouping	Edit...
Formatting	Edit...
Appearance	Edit...

Properties help   Apply

Project Browser - ARCHITECTURAL_LEXF_T... ✕

- ⊞ Legends
- ⊟ Schedules/Quantities
  - Abbreviations
  - ABBREVIATIONS - Structural
  - Casework Schedule
  - CIVIL
  - DOOR AND FRAME PAINT SCHEDU
  - DOOR SCHEDULE
  - EGRESS SCHEDULE
  - FURNITURE SCHEDULE
  - GLAZING SCHEDULE
  - LIGHTING FIXTURE SCHEDULE
  - **Multi-Category Schedule**
  - PANEL SCHEDULE
  - ROOM LEGEND
  - ROOM SCHEDULE
  - Sheet List
  - SIGNAGE SCHEDULE
  - View List
  - WINDOW SCHEDULE
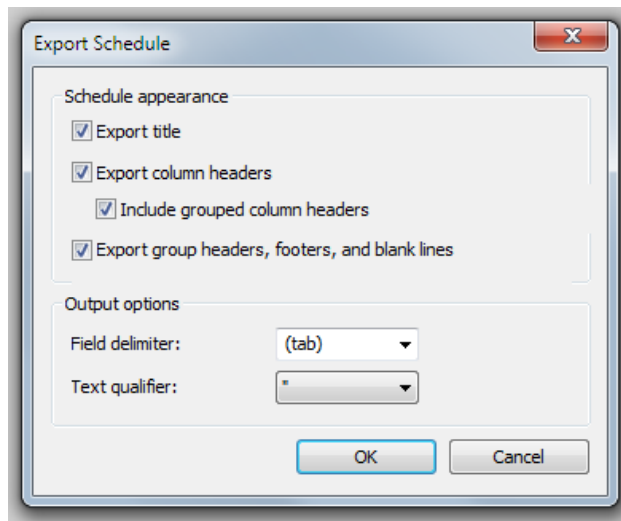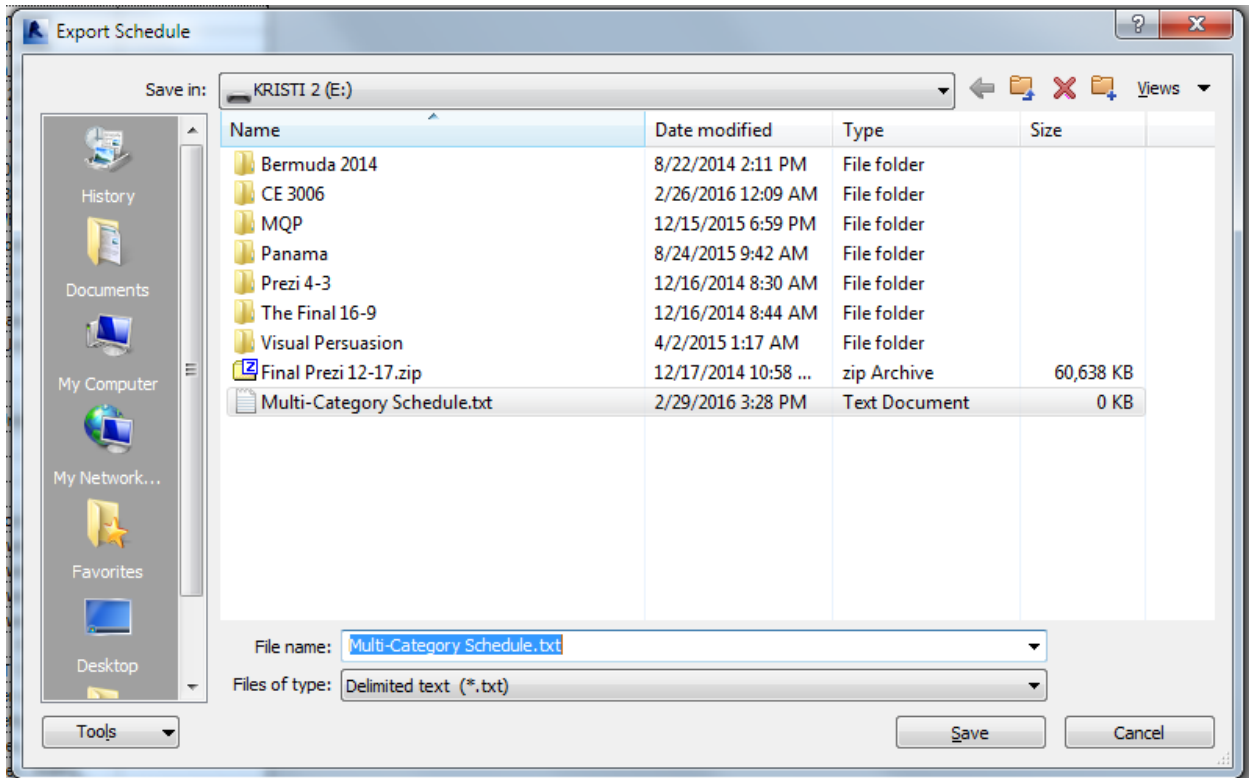 - WINDOW TREATMENT SCHEDULE

\<Multi-Category Schedule\>

A	B	C	D	E
Category	Count	Family	Type	Air Flow
Furniture Systems	1	3 FORM 10'1	3 FORM 10'	
Generic Models	1	3 form Base	3 form Base	
Generic Models	1	3 form Base1	3 form Base	
Generic Models	1	3 form Base3	3 form Base	
Casework	2	3form_frame	3form_frame	
Plumbing Fixtures	4	0495.221	0495.221	
Plumbing Fixtures	7	2856.128	Water Closet Wall	
Plumbing Fixtures	7	6047.121	6047.121	
Plumbing Fixtures	1	6590.001	6590001.020	
Casework	3	293284	293284 2	
Casework	2	293309	MCWF361836	
Mechanical Equipmen	9	Air Conditioner	Air Conditioner, Sp	
Lighting Fixtures	4	APXEL-Housing	APXEL-Housing	
Generic Models	1	ATM_Freestanding	ATM_Freestanding	
Doors	6	Automatic Sliding	All Glass	
Casework	1	Base Cabinet-2 Bi	15" Under Cab Ad	
Casework	14	Base Cabinet-4 Dr		
Casework	4	Base Cabinet-Dou		
Casework	1	Base Cabinet-Dou	24" Under Cab Ad	
Casework	5	Base Cabinet-Filler		
Casework	2	Base Cabinet-Singl		
Curtain Panels	150	Basic Wall		
Specialty Equipment	2	Bradley-Washroo	Surface-Mounted	
Casework	1	Casework 3	Casework 2	
Casework	1	Casework 4	Casework 2	
Casework	1	Casework 5	Casework 5	
Casework	1	Casework 6	Casework 6	
Specialty Equipment	2	Cash_Register-To	16" x 18" x 14" -	
Generic Models	1	CAST STONE BA	CAST STONE BA	
Generic Models	2	Caster wheel - Fe	Caster wheel - Fe	
Specialty Equipment	2	Change_Table-Flip	Polyethylene-Whit	
Furniture	1	Connex_Seating_	Connex_Seating_	
Furniture	1	Connex_Seating_	Connex_Seating_	
Casework	1	counter1	counter	
Generic Models	6	Counter support	Counter support	
Curtain Panels	4	Curtain Wall Panel	IG-Acid Etched	
Curtain Panels	24	Curtain Wall Panel	SPANDREL - WHI	
Curtain Panels	69	Curtain Wall Panel	Curtain Wall Panel	
Curtain Panels	6	Curtain Wall Panel	IG-Translucent Mir	
Curtain Panels	72	Curtain Wall Panel	Curtain Wall Panel	
Curtain Panels	1	Curtain Wall Panel	Spandrel - Dark Gr	
Curtain Panels	270	Curtain Wall Panel	Curtain Wall Panel	
Curtain Panels	22	Curtain Wall Panel	Curtain Wall Panel	
Generic Models	1	Curtain Wall Sill E	Curtain Wall Sill E	
Generic Models	1	Curtain Wall Sill E	Curtain Wall Sill E	
Generic Models	3	Deal Tray - Stainle	Deal Tray - Stainle	
Generic Models	2	Defibrillator		
Specialty Equipment	2	Dispenser-Paper_	Metal-Stainless_St	
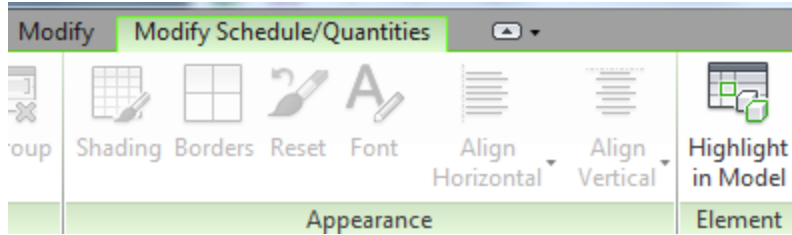
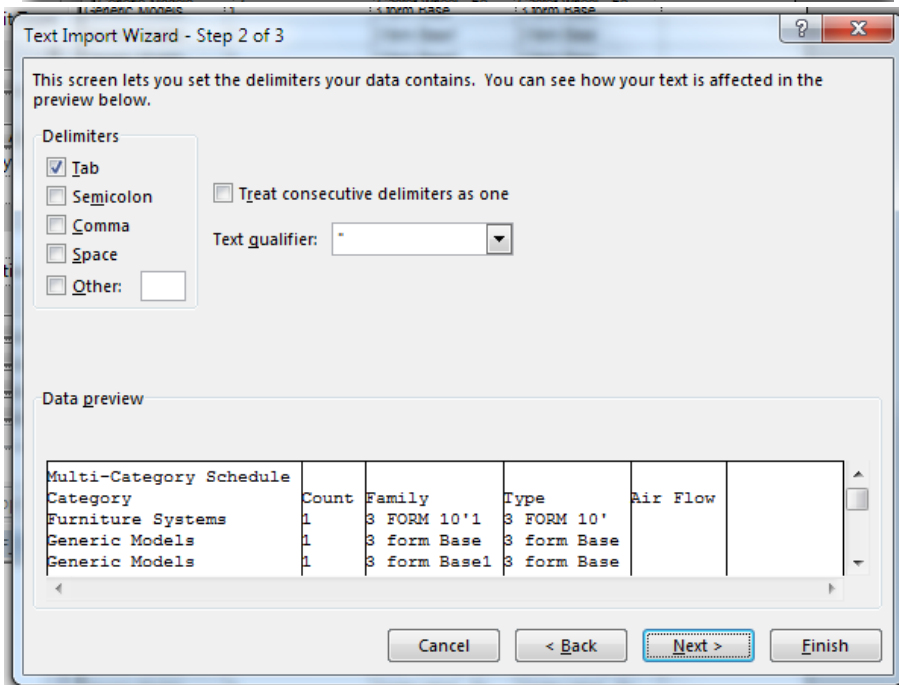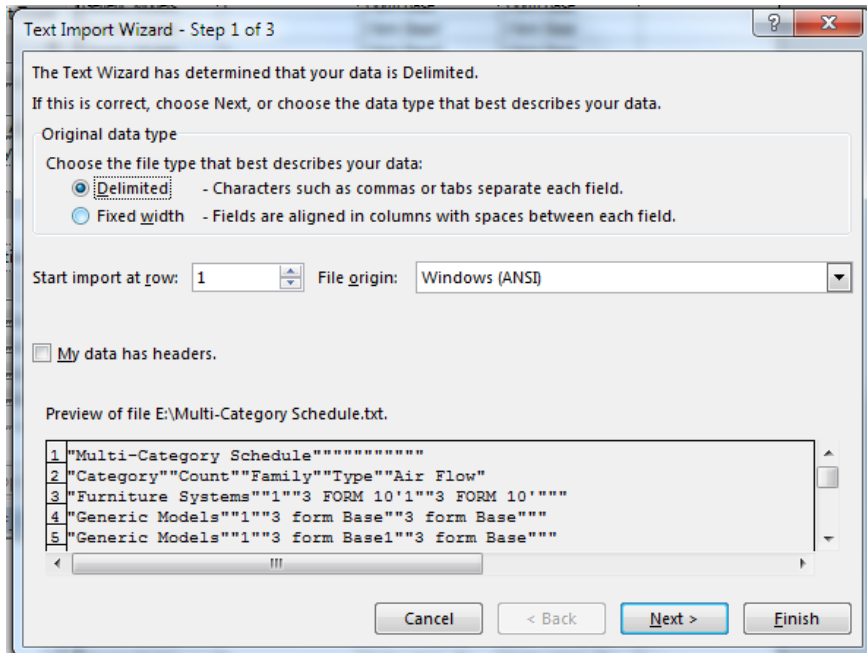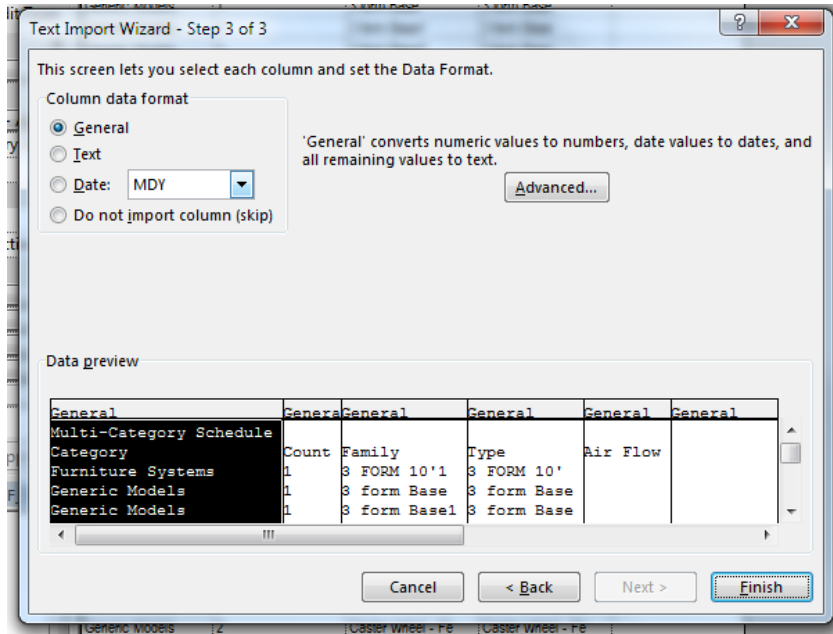By going to the "Modify Schedule/Quantities" ribbon, you may use the "highlight in model" option and this will allow you to view the asset in the model.
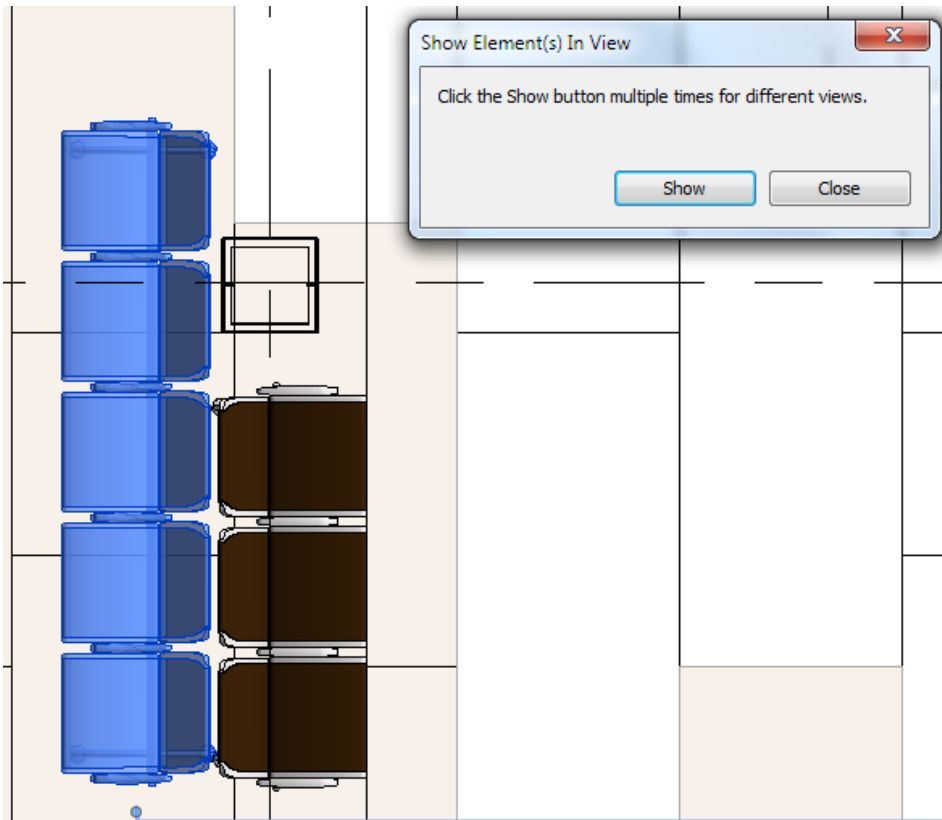
From here, you may export the schedule from the "File" "Export" option. By clicking okay for schedule appearance and continuing by licking next and finish, the file will be exported as a text file that may be imported to an Excel spreadsheet.

Text Import Wizard - Step 3 of 3

This screen lets you select each column and set the Data Format.

Column data format
- (•) General
- ( ) Text
- ( ) Date: MDY
- ( ) Do not import column (skip)

'General' converts numeric values to numbers, date values to dates, and all remaining values to text.

[Advanced...]

Data preview

General	General	General	General	General	General
Multi-Category Schedule					
Category	Count	Family	Type	Air Flow	
Furniture Systems	1	3 FORM 10'1	3 FORM 10'		
Generic Models	1	3 form Base	3 form Base		
Generic Models	1	3 form Base1	3 form Base		
Generic Models	1	3 form Base1	3 form Base		

[Cancel] [< Back] [Next >] [Finish]

Multi-Category Schedule.txt - Excel

	A	B	C	D	E	F
1	Multi-Category Schedule					
2	Category	Count	Family	Type	Air Flow	
3	Furniture Systems	1	3 FORM 10'1	3 FORM 10'		
4	Generic Models	1	3 form Base	3 form Base		
5	Generic Models	1	3 form Base1	3 form Base		
6	Generic Models	1	3 form Base3	3 form Base		
7	Casework	2	3form_frame	3form_frame		
8	Plumbing Fixtures	4	495.221	495.221		
9	Plumbing Fixtures	7	2856.128	Water Closet Wall mounted		
10	Plumbing Fixtures	7	6047.121	6047.121		
11	Plumbing Fixtures	1	6590.001	6590001.02		
12	Casework	3	293284	293284 2		
13	Casework	2	293309	MCWF361836		
14	Mechanical Equipment	9	Air Conditioner	Air Conditioner, Split System, Fan Coil Unit		
15	Lighting Fixtures	4	APXEL-Housing	APXEL-Housing		
16	Generic Models	1	ATM_Freestanding	ATM_Freestanding		
17	Doors	6	Automatic Sliding Door	All Glass		
18	Casework	1	Base Cabinet-2 Bin	15" Under Cab Admin		
19	Casework	14	Base Cabinet-4 Drawers			
20	Casework	4	Base Cabinet-Double Door & 2 Drawer			
21	Casework	1	Base Cabinet-Double Door Sink Unit	24" Under Cab Admin		
22	Casework	5	Base Cabinet-Filler			
23	Casework	2	Base Cabinet-Single Door & Drawer			
24	Curtain Panels	150	Basic Wall			
25	Specialty Equipment	2	Bradley-Washroom-Accessories-Waste-Receptacles-355	Surface-Mounted		

Multi-Category Schedule

Appendix D: Structural Document Components

Loadings from Structural PDF documents for the areas of the structure

LOADS

THE BUILDING IS DESIGNED FOR THE FOLLOWING LOADS.
1. LIVE LOADS (UNIFORMLY DISTRIBUTED)

    A. LOBBY/CORRIDORS   100psf
    B. PARKING   40psf
    C. TERMINAL   100psf
    D. TERMINAL ROOF   20psf

Double Tee Schematic

TYPICAL PRETOPPED DOUBLE TEE DETAIL
SCALE: 3/4" = 1'-0", SG105
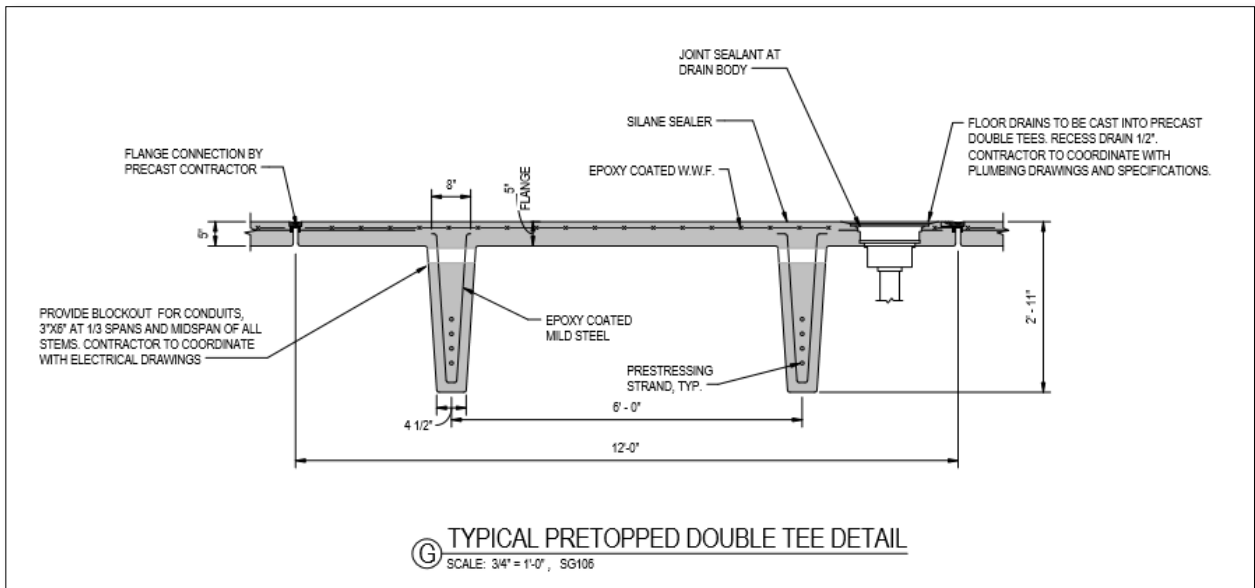
Appendix E: Calculations for Steel Framing

Lobby Framing Structural Analysis

Columns = W12×65
girder = W12×65
exterior beams = W12×40
interior beams = W12×19
· 5ft 5in spacing
A992 steel
loading = 100psf LL

W12×19   span = 26' 6"   Spacing = 5'5"

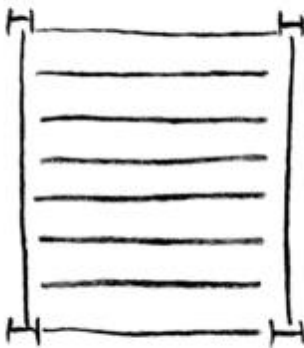$W_u = 1.2 DL + 1.6 LL$

$W_u = 1.2 (19 lb/ft) + 1.6 (100psf)(5.417 ft) = 889.52 \ lb/ft$

$M_u = \dfrac{W_u L^2}{8}$

$M_u = \dfrac{(889.52 \ lb/ft)(26.5 ft)^2}{8} = 78.083 \ ft\text{-}kips$

$Z_x \geq \dfrac{M_u}{\Phi_b F_y}$

$Z_x \geq \dfrac{(78.083 \ ft\text{-}kips)}{(0.9)(50 ksi)} = 20.822 in^3$

$Z_x = 24.7 in^3 > 20.822 in^3$ ✓

deflection

$w_T = \frac{(100psf)}{2}(5.417 ft) + 19 lb/ft = 289.85 lb/ft$

$\Delta_T = \frac{5 \, w_T \, L^4}{384 \, E \, I}$

$\Delta_T = \frac{5(289.85 lb/ft)(26.5ft)^4}{384(29\times10^6 psi)(533 in^4)} = 0.2081 in$

$\Delta_T < L/240 \rightsquigarrow 0.2081 in < 1.325 in$ ✓

<u>W12×40</u>   span = 26'6"   spacing = 5'5"

$w_u = 1.2(40 lb/ft) + 1.6(100 psf)(5.417 ft) = 914.72 lb/ft$

$M_u = \frac{(914.72 lb/ft)(26.5 ft)^2}{8} = 80.295 \, ft \, kips$

$Z_x > \frac{(80.295 \, ft \, kips)}{(0.9)(50 ksi)} = 21.412 \, in^3$

$Z_x = 57 in^3 > 21.412 in^3$ ✓

deflection

$w_T = \frac{(100 psf)}{2}(5.417 ft) + 40 lb/ft = 310.85 lb/ft$

$\Delta_T = \frac{5(310.85 lb/ft)(26.5 ft)^4}{384(29\times10^6 psi)(307 in^4)} = 0.3874 in$

$\Delta_T < L/240 \rightsquigarrow 0.3874 in < 1.375 in$ ✓

Appendix F: Calculations and Corresponding Spreadsheet for Double Tees

Properties of Concrete		
fc'(psi)=	6000	
fci(psi)=	4000	
Density of Conrete (lb/ft^3) =	150	
Ec' =	4695982.33	$33 \times w_c^{1.5} \sqrt{f_c'}$
Eci =	3834253.51	$33 \times w_c^{1.5} \sqrt{f_c'}$

Properties of Prestressing Steel		
fpu (ksi) =	270	
Number of Strands =	20	
Aps (in^2) =	0.217	
Eps (psi) =	2.85E+07	$0.7 * A_{ps} * \#of\ strands * f_{pu}$
Pi (k) =	820.26	

Section Properties		
Rectangular Beam		
Width,b (in) =	144	
Height,h (in) =	35	
Length (in) =	720	
Area (in^2) =	1095	$b \times h$
Inertia (in^4) =	92804.7945	$\frac{1}{12}bh^3$
cb=ct (in) =	26.9863014	l
Section Modulus,Sb (in^3) =	3438.95939	$h/2$
Volume/Surface (in) =	2.88848957	

Loads		
Live Load (k/f) =	1.2	40psf
Dead Load (k/f) =	0	
Self Weight (k/ft) =	1.140625	

ct=	8.01369863	
St=	11580.76923	

Prestress Losses

Elastic Shortening		
Kes=	1	
Kcir=	0.9	
e (in)=	11	
Msw (k-in) =	6159.375	$\frac{w_{sw} \times L^2}{8}$
fcir (psi)=	906.644	$f_{cir} = K_{cir}\left(\frac{P_i}{A_g} + \frac{P_i e^2}{I_g}\right) - \frac{M_{sw}e}{I_g}$

Creep of Concrete		
Kcr=	2	
Mdl (kp-in) =	0	
fcds (psi) =	0	$\frac{M_{DL}e}{I}$
CR (psi) =	11004.877	$CR = K_{CR}\left(\frac{E_{PS}}{E_c'}\right)(f_{cir} - f_{cds})$

Width,W (in) =	144						
Height,H (in) =	35						
b	4.5						
a	8						
h	5						
H-h	30						
Length (in) =	720						
cb	26.9863						
Ct	8.0137						
Area (in^2) =	1095						
Inertia (in^4) =	92804.8		Shape	I	A	y	A*y	d	A*d²
Section Modulus,Sb (in^3) =	3438.96			in⁴	in²	in	in²	in	in⁵
Section Modulus,St (in^3) =	11580.8		Flange	1500	720	32.5	23400	5.5137	21888.6
Volume/Surface (in) =	2.88849		Web 1	13695	187.5	16.4	3075	10.5863	21013.1
			Web 2	13695	187.5	16.4	3075	10.5863	21013.1
			Sum =	28890	1095		29550		63914.8

	1271550
e @ transfer Length (in) =	1.195
Msw @ transfer length (k-in)	1108.5

TOTAL LOSS (PSI)=	25646.683		13.56967373
JACKING FORCE AFTER LOSSES (k) =	708.95339		

$$P_i - (TL * \# \; of \; strands * A_{ps})$$

Critical Stress Calculations

Fse = (0.7 x fpu) ksi	189	
Tl= (Transfer Length –in) =	34	Design Aid 15.3.4

Ps forces after losses

Transfer @ Release

Msw,T (k–in)=	1108.4974	$\dfrac{W_{sw} \times T_L}{2} \times (L - T_L) * 12$
fcir(ksi)=	1.5053162	
ESt (ksi)=	11.189013	$f_{cir} = K_{cir}\left(\dfrac{P_i}{A_g} + \dfrac{P_i e^2}{I_g}\right) - \dfrac{M_{sw,T}e}{I_g}$
Loss ESt (k)	48.560317	$(ES_T \times A_{ps} \times \# of \; strands)$
Po1(k)=	771.69968	$P_i - ES_T$

Midspan @ Release

Msw,M (k–in)=	6159.375	
ESM (ksi)=	6.7390834	
Loss ESM (k)	29.247622	$ES_M \times A_{ps} \times \# of \; strands$
Po2(k)=	791.01238	

Midspan @ Service

Msw (k–in)=	6159.375
Msdl (k–in)=	0
Mll (k–in)=	6480
Po3(k)=	738.234

	Transfer @ Release		Midspan @ Release		Midspan @ Service	
""""units are in psi"""""	f b	f t	f b	f t	f b	f t
Po/A	704.74857	704.7485692	722.3857336	722.3857336	674.1863014	674.1863
Po.e/S	2468.391	-732.999367	2530.165429	-751.343541	2361.34629	-701.212
Msw/S	-322.3351	95.71880535	-1791.057788	531.8623381	-1791.057788	531.86234
Msdl/S	0	0	0	0	0	0
Mll/S	0	0	0	0	-1884.290933	559.54832
Total	2850.8045	67.46800751	1461.493374	502.9045307	-639.8161297	1064.385
PCI Limits	2800	-474.341649	2800	-474.341649	-929.5160031	4200
Limit Check	NOT In Limits	Compression OK	In Limits	Compression OK	Class U	In Limits

Deflection Calculations

		$\dfrac{P_{02}eL^2}{8E_{ci}I_g}$
Camber (in)=	1.5845273	
Def due to SW (in) =	0.9347149	$\dfrac{5w_{sw}L^4}{384E_{ci}I_g}$
Def due to SDL (in) =	0	$\dfrac{5w_{DL}L^4}{384E_c'I_g}$
If Uncracked		
Def due to LL (in) =	0.8029193	$\dfrac{5w_{LL}L^4}{384E_c'I_g}$

Appendix G: Additional Robot Structure Analysis Components

Below are the results from the simulation calculations the team ran through Robot Structural Analysis Professional.

Reactions in the coordinate system: global - Cases: 1 2

Node/Case		FX (kip)	FY (kip)	FZ (kip)	MX (kip-ft)	MY (kip-ft)	MZ (kip-ft)
1/	1	0.18	0.73	3.57	-3.95	0.99	-0.00
1/	2	4.21	14.19	47.74	-77.13	22.81	-0.00
3/	1	0.18	-0.73	3.57	3.95	0.99	0.00
3/	2	4.22	-14.19	47.95	77.07	22.82	0.00
5/	1	-0.18	-0.73	3.57	3.95	-0.99	-0.00
5/	2	-4.22	-14.19	47.95	77.07	-22.82	-0.00
7/	1	-0.18	0.73	3.57	-3.95	-0.99	0.00
7/	2	-4.21	14.19	47.74	-77.13	-22.81	0.00
Case 1	DL1						
Sum of val.		0.00	0.00	14.29	-0.00	0.00	0.00
Sum of reac.		0.00	0.00	14.29	270.39	-189.29	0.00
Sum of forc.		0.0	0.00	-14.29	-270.39	189.29	0.0
Check val.		0.00	0.00	-0.00	-0.00	0.00	0.00
Precision		3.15790e-014	8.81460e-029				
Case 2	LL1						
Sum of val.		0.00	0.00	191.38	-0.12	0.00	0.00
Sum of reac.		0.00	0.00	191.38	3627.87	-2535.83	0.00
Sum of forc.		0.0	0.0	-191.38	-3627.87	2535.83	0.0
Check val.		0.00	0.00	-0.00	-0.00	0.00	0.00
Precision		3.50678e-014	2.06199e-028				

Innovative Uses of BIM for Facility Management

Kristen Hunt
Juan Torres Betancur

Submitted to:

Professor Guillermo Salazar

3/4/2015
Worcester Polytechnic Institute
Massachusetts Port Authority

Table of Contents

Table of Figures

1.0 Introduction

The Architecture, Engineering and Construction Industry was revolutionized with the implementation of Building Information Modeling (BIM). The construction industry has seen an increase from 28% to 71% in usage from 2008 to 2013 (McGraw-Hill Construction, 2012). BIM increases communication and organization while decreasing the inefficiencies of the industry such as unplanned difficulties with processes and interfering components. The implementations of the improving technology of BIM allow companies to see "faster project approvals, increased positive client interactions and higher client satisfaction" (Gaudiosi, 2015). The programs and uses of BIM are continually advancing to include new applications and purposes.

BIM is valuable to numerous professions throughout the lifecycle of a building. It is employed for the design, construction, operation and renovation phases for any given building or structure. Multiple software have been developed to provide the capabilities for each of the phases and professions. Specific programs highlight and focus the needs for the particular function. Between phases the models and information must travel between different professionals and also possibly different software. This handover segment of the lifecycle of a building, like other aspects included in BIM is improving and being researched for efficient practices.

The handover process between the design and construction phase to the operation and maintenance phase of the building can contain large amounts of information that have value to different people. One portion of this handover process that is detrimentally affecting the process is a concept referred to as the tsunami effect. The tsunami effect explains how the model from the creation of the building has all the information needed for the structural analysis, construction, design and other components of the building that may not be crucial for its operation after completion, as seen on the left half of Figure 1 below.
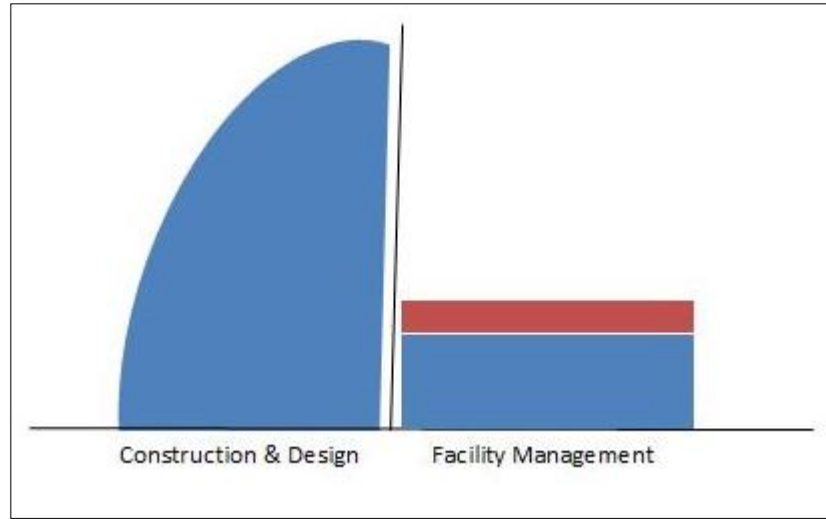
Figure 28: Graphical Representation of Tsunami Effect (Adapted from Alvarez-Romero, 2014)

All of this extra information, from the perspective of the facility manager, is the tsunami that has to be cut down and refined to accommodate the team for maintaining the building. The remaining information still useful to the facility management process is the blue rectangle on the right half of the figure above. On the other hand, some information needed for the processes after the completion of the building may not be included in the model handover because it was not originally vital for the design or construction. Therefore, the attributes would have to be added for the model to benefit the facility management team and this is included in the figure above as the red rectangle.

Based on this concept of the tsunami effect and the goals of Massport, the team developed the purpose of this project. The focus will be to refine and prepare Facilities Management Building Information Models to more efficiently serve the lifecycle functions for operation, maintenance and space utilization of a constructed facility.

The team will refine a preliminary model, provided by Massport, to facilitate the facility management operations and prepare the model for integration with facility management (FM) software to improve efficiency of the facility management process. To do this the team will distinguish the necessary and unnecessary attributes included and not included in the current provided model. Then, the current model will be refined to meet the requirements for the purpose of facility management, and lastly, the team will prepare the modified model for integration software to improve for facility management use.

The project will result in a modified model with the desired attributes, research of BIM-FM integration systems and piloted software with the prepared model.

2.0 Background

2.1 What is BIM?

BIM, which stands for Building Information Modeling, is a concept used to incorporate the information and data for a building into an interactive model created on software. According to National BIM Standard (NBIMS), "a building information model is a 3D digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward" (NBIMS, 2015).

Building information modeling is not necessarily a new technology but in recent years numerous new applications with BIM have come about. "The adoption of BIM has grown from 28% to 71% in the construction industry between 2008 and 2013 in the first and second BIM SmartMarket Report research studies, published by McGraw-Hill Construction in 2006 and 2009" (McGraw-Hill Construction, 2012). BIM has a wide range of uses for professions across fields of practice. BIM can be used for the design, construction, and maintenance and operation of the building. The graphic below in Figure 2 displays the uses of BIM throughout the life of a building.
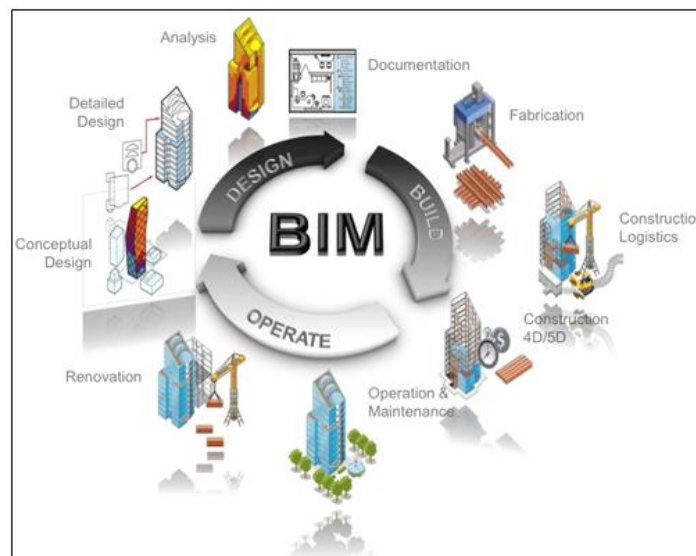

Figure 29: BIM through the lifecycle of a building (Syncronia, 2011)

The architect may use BIM to initially design the building before creation. The civil engineer or structural engineer will take the design and continue using the BIM process to calculate the infrastructure and materials needed for a stable building. Along the way other engineers may perform analyses, such as energy loss and orientation on the site. BIM programs can also be used for the scheduling and cost analysis for the project manager. And then after the model is implemented to complete construction, the model will be transferred for application for the operation of the building. The model can continue through the steps of use multiple times in the case of renovations. BIM is a valuable asset for the life-cycle of the building.

Models are made for numerous profession and purposes; therefore they differ on different levels. During creation and after completion the product is modified for each use, not only is the content and software specific but also the amount and formation of information is geared towards the function of the model. The amount of information or detail in a model can be referenced through the Level of Detail (LoD). LoD can also be Level of Development, which "is the degree to which the element's geometry and attached information has been thought through- the degree to which project team members may rely on the information when using the model" (BIM Forum, 2013). LoDs are rated on a number scale and different levels along the scale represent specified descriptions for the corresponding details. Common ratings are 100, 200, 300, 350, 400, and 500. Level 0 signifies an item not modeled, level 100 refers to a conceptual model, and level 200 is a generic or representational model and the details increase in amount and value as the levels increase. Level 500 would correspond to a record model (Burdi, 2011). Examples of the detail included in certain levels can be viewed in Figure 3 below (BIM Forum, 2013).
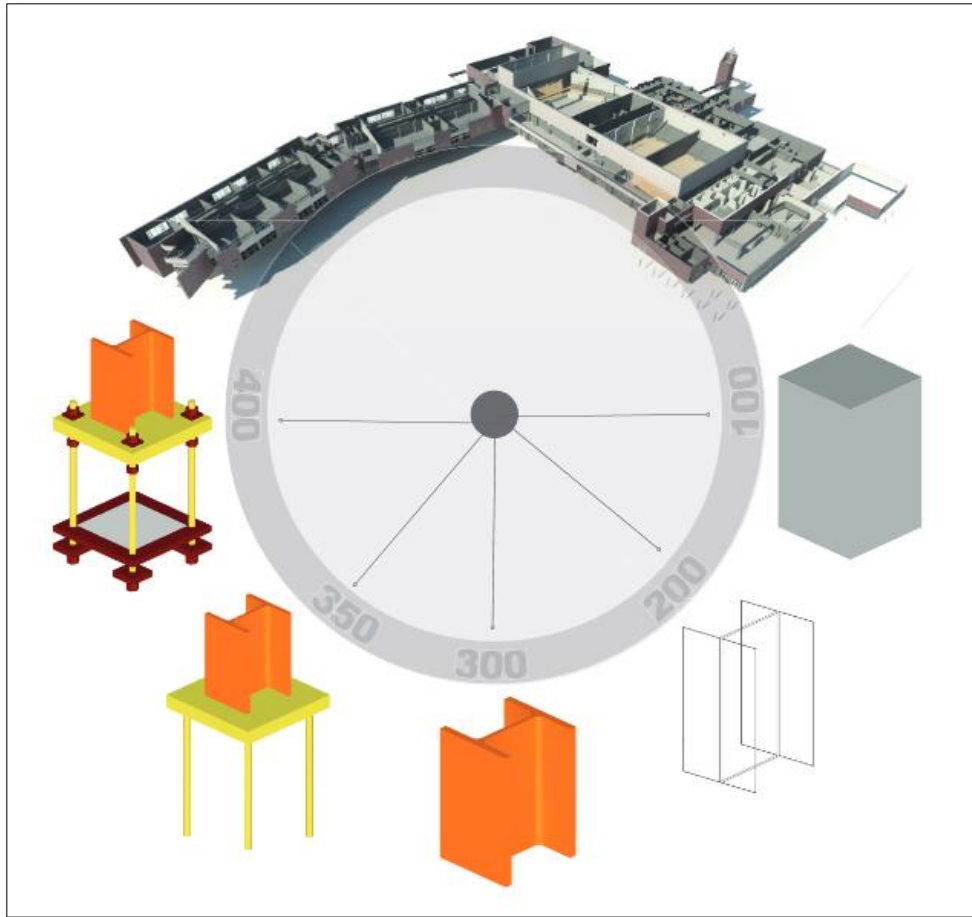
Figure 30: Level of Detail Examples (BIM Forum, 2013)

Overtime organizations have created ways to attempt to make BIM more useful and normalized. Codes and standards of use have been devised across the globe. The ultimate purpose of these standards is to allow a normalized process and product for all BIM as to allow easier communication and compatibility. One such organization is OmniClass, which is "a standard for organizing all construction information" (OmniClass, 2015). Another well-known set of codes is the Construction Operations Building information exchange, or COBie. The goal behind the creation of COBie is to assure that the information required is carried through the lifecycle of a building, including facility management, in a way that it can be productively employed (East, 2012). In some areas around the world these standards are required, like in the United Kingdom, however elsewhere the normalized standards have not been as strongly enforced so there still remain discrepancies from model to model.

2.2 Massport

For the duration of the project, the team will be collaborating with Massachusetts Port Authority, commonly known as Massport, at Boston Logan International Airport. Massport is an independent public authority dealing with transportation means throughout Massachusetts. As any organization responsible for facilities or buildings, in the modern technology age, Massport has turned to innovative software for efficient operation. The sections following will set the scene for Massport, its current BIM usage and its future endeavors.

2.2.1 Massport History and Overview

Massport was established in 1956 and became operational on February 17, 1959. It was created as an independent public authority as not to draw funds from the government or the taxpaying people. At the time of its creation, it was able to fund and sustain itself through "the sale of revenue bonds, charges to users of its facilities and income from investments" (Massport, 2015a). Today Massport is "a world class organization of people moving people and goods – and connecting Massachusetts and New England to the world – safely and securely and with a commitment to our neighboring communities" (Massport, 2015b). Under Massport's jurisdiction is Boston Logan International Airport, Worcester Airport, Hanscom Field, Port of Boston and numerous other properties.

Logan International Airport, located in Boston Massachusetts, provides flights to more than 100 countries and areas around the world through the collaboration with nearly 50 airline companies (Massport, 2015b). First opened in 1923 and officially named the General Edward Lawrence Logan Airport in 1943, the airport has had numerous expansions and advances in its field through the ninety plus years (Massport, 2015a). Logan Airport currently has four terminals and local parking garage structures. The most recent completion to the complex at Logan Airport was the parking garage.

2.2.2 Massport's Implementation of BIM

Recently, Massport has been implementing various stages and uses of BIM. Models have been created of the new constructed parking garage and one of the terminals. These models were developed following the completed construction to represent the as-built situations; however, they are in the phase before modifications are enacted for facility management use. Before these

models are refined for the utilization in the operations of the building, the proper information and attributes of certain components have to be collected. Massport is working with two companies using three different techniques to gather the desired attributes that will be included in the model for facility management (Burdi, Personal Communication, 2015). In the past years, facility management teams at Logan Airport have been operating with IBM Maximo. But the full potential of the benefits of models and BIM have not been explored to improve these processes.

2.2.3 The Future of Massport with BIM

Teams working with BIM at Massport have created a Massport Building Information Modeling Roadmap for the current and future implementation of BIM. The roadmap explains key areas where BIM can improve throughout Massport. Massport's mission for BIM is stated below:

"Massport will utilize BIM and related technologies to empower its staff and service providers to design and build outstanding structures, and then manage and sustain these facilities and assets to meet Massport's mission. As stewards of these digital assets, Massport will maintain BIM,GIS, and facility maintenance asset data to support strategic planning, sound decisions, sustainability, environmental responsiveness, and improved processes to add value to managing the building lifecycle, and to aid Massport in better reinvestment of available funds based upon organizational missions and operational requirements" (Massport, 2015c).

Down the road the ideal result for Massport would be to have a BIM portfolio complete to 100% with reliable data and access to personnel to maximize efficiency. Steps along the way included in the roadmap are to "normalize BIM based project management and project management training, optimize BIM to FM- integrated asset management, and institutionalize enterprise asset management" (Massport, 2015c). These three phases are distributed through smaller goals outlined on a timeline spanning from 2014 to 2020 within the roadmap. The roadmap can be viewed through the Massport website.

2.3 BIM-FM Integration Software

Throughout the history of computer aided building design, the programs, applications and software have continued to specify and improve for different desires. All components of the

design, construction and operation of a building can be documented and displayed through software. Depending on the need of the user and purpose of the information, certain types of programs are more suitable than others. This section explores the software of BIM, FM and integrators: their purposes, features, benefits and capabilities.

2.3.1 BIM Software

The different sectors of construction require specialized BIM software, and although many are compatible with each other, each software program is not interchangeable. This section will focus on widely used BIM software programs in architecture, MEP (mechanical, electrical, and plumbing), structures, and construction. All of these programs create data for the final BIM project and thus, it is very important to understand the common uses and capabilities of these programs.

2.3.1.1 Architecture

There are two very popular architecture programs used in the construction industry. Each has different functionality but tend to reach a similar conclusion with the product. The first that this section will cover is Revit Architecture by Autodesk, and then ArchiCAD by Graphisoft.

Revit Architecture focuses on the capability to create different architectural features such as a curtain wall, floor, roof, room and area, stairs, anti-aliasing and loadable component for design. The primary use of Revit Architecture is for a firm to create a 3D representation of the model that they believe the owner is visualizing. Since this software is from the Autodesk family, it is easily transferred into other Autodesk programs such as: Revit MEP, Revit Structure, and Navisworks. This program is made to be flexible with the design features. It is designed to allow the user to easily fix wall joints and the loadable components such as doors and windows. Revit Architecture also has a layout of phase and phase filters. This allows the user to easily see the process of either demolition or construction. Its 3D feature is axonometric as well, which constricts the ease of virtually walking around the building or structure designed (AE, 2013).

Although ArchiCAD is similar to Revit Architecture in that it focuses on the designing of a structure for an owner, ArchiCAD has a more intuitive layout for its commands. It has perspective views that embrace the option to virtually walk around the designed structure. There are also drafting tools that easily incorporate the option of elevations and sections, and the

energy modeling systems work well. However, the energy modeling is not as powerful as the Ecotect and Green Building Studio from Revit Architecture (AE, 2013).

For the most part, there are advantages to each. While ArchiCAD has working templates that do not leave the user starting from the creation of templates and standards, Revit Architecture can easily convert to AutoCAD, and this is the program most widely used in the industry. In Figure 4 and 5, below, you can see side-by-side comparisons of the layout for both Revit Architecture and ArchiCAD.
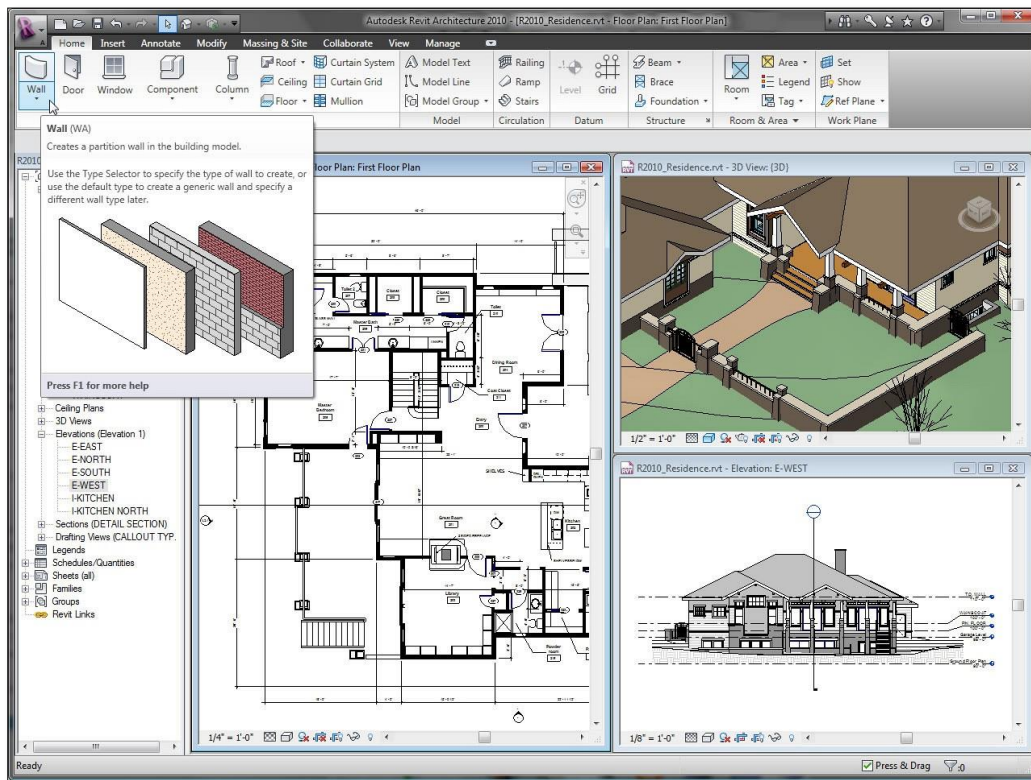

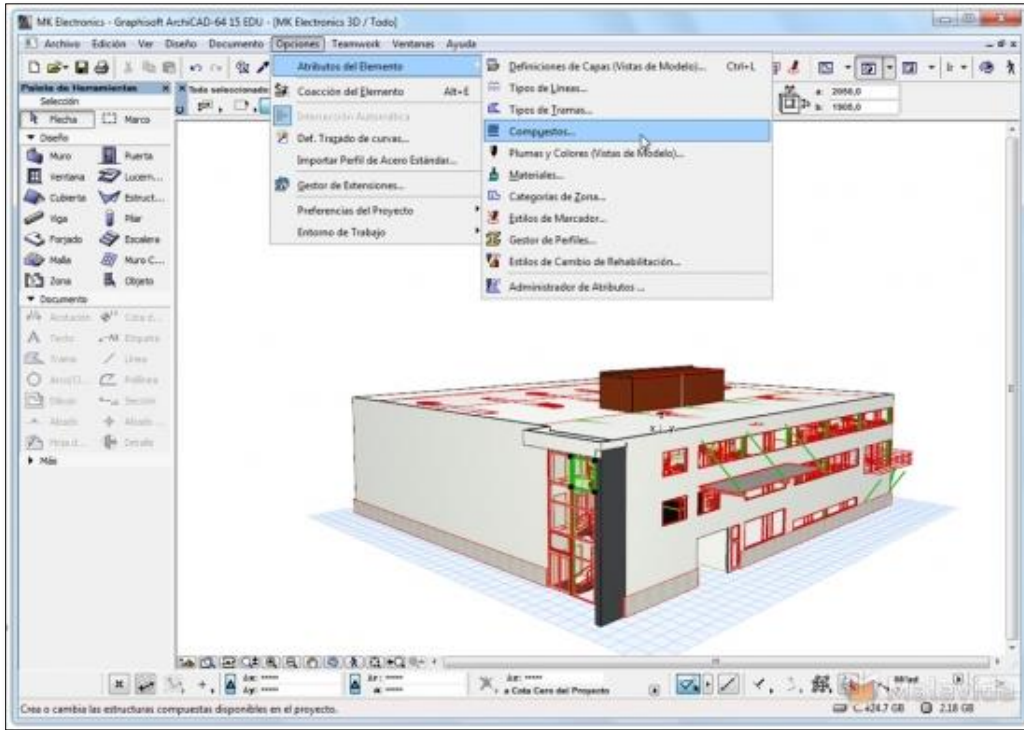**Figure 31: Revit Architecture Interface (Autodesk, 2013)**

Figure 32: ArchiCAD Interface (ArchiCAD, 2015)

3.2.1.2 MEP

MEP stands for mechanical, electrical, and plumbing. This important component of a construction project is often coordinated through collaboration in BIM because of the visualization capabilities of the BIM models. The models can help each line of work find clashes in the design of the mechanical, electrical, and plumbing systems. This allows foresight in the designing process since the clash is detected before the construction is undertaken, effectively reducing related costs and time.

Two popular programs for this kind of coordination are Autodesk Revit MEP and Bentley Hevacomp Mechanical Designer. Both focus on the MEP coordination and energy analysis of a design but have different layouts that end up affecting the learning curve of the software.

Revit MEP follows the same interface as the other Revit software programs. This allows a user who is familiar with the other Revit software programs to easily understand and use the MEP program. The main purpose of the MEP version is to "help mechanical, electrical, and plumbing engineers keep design data coordinated, minimize errors, and experience enhanced

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collaboration with engineering and architecture teams (Autodesk, 2015a)." The interface of the software allows the different members of the MEP team to see each other's drawings. It also features "automatic sizing and flow calculation for maximum performance (Autodesk, 2015a)." This program also coordinates with Revit Architecture and Revit Structures which means there are never issues with converting data amongst the different software.

Another popular MEP software program is Bentley Hevacomp Mechanical Designer. This software focuses on "engineering-quality building load and energy calculations (Bentley, 2015)." This is accompanied by duct and pipe systems. The model utilizes DXF files and includes 3D visualization tools. One of the differences between this software and Revit MEP is that it includes code checking. This code checking is available for building designs and can be changed to be country specific (Bentley, 2015). Figures 6 and 7 below illustrate the visual differences between using Revit MEP and Bentley Hevacomp Mechanical Designer, respectively.
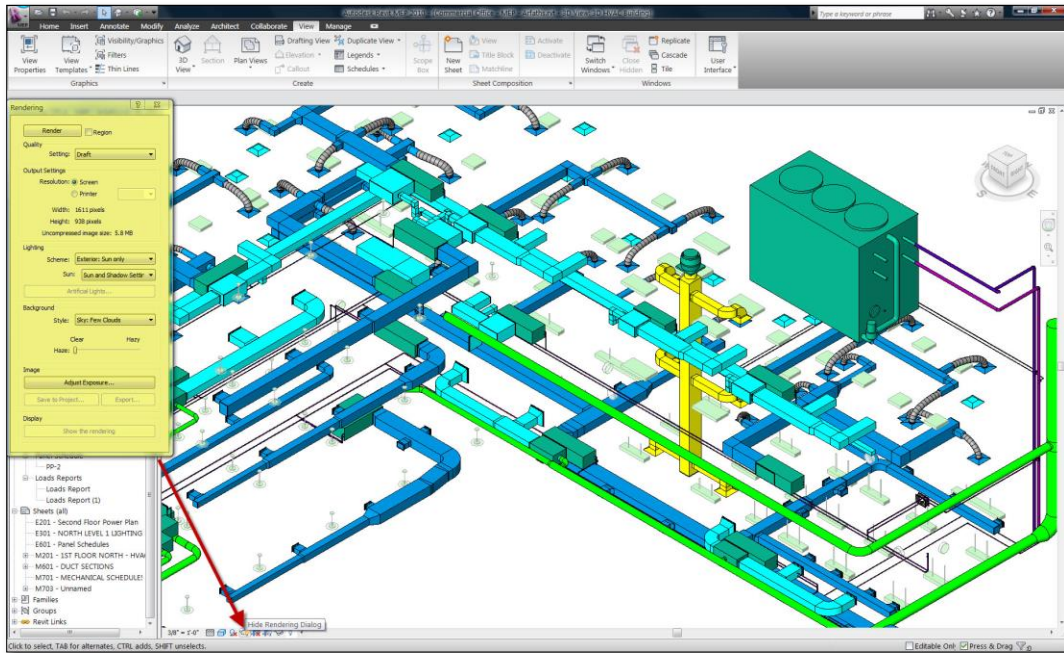

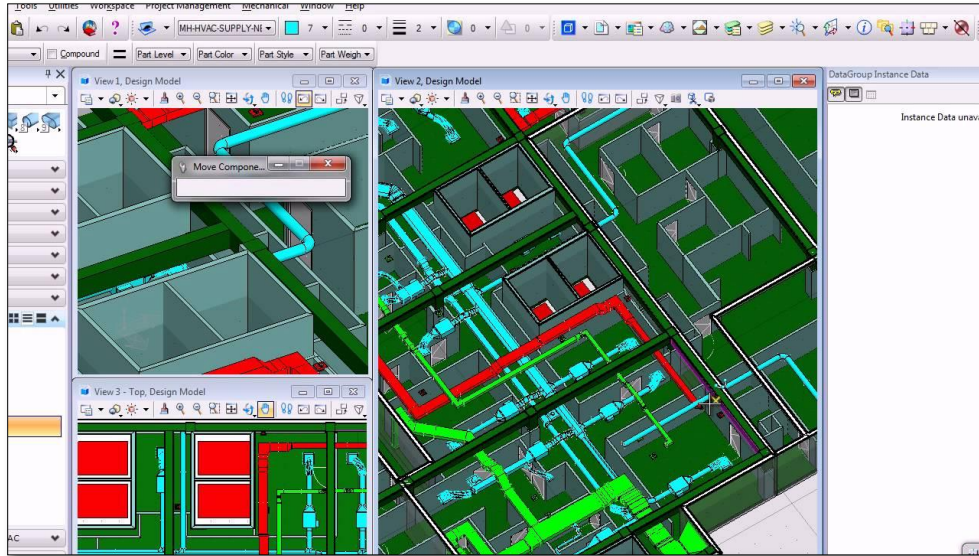**Figure 33: Revit MEP Interface (Cantonese, 2014)**

Figure 34: Bentley Hevacomp Interface (Cortes, 2012)

3.2.1.3 Structure

The structural analysis of a project has been evolving with the introduction of BIM structural capabilities. Not only can projects be designed through BIM software, specifications of materials, dimensions, and structural analysis can also be incorporated into the construction and design phase. Two programs that work on this structural field are Autodesk Revit Structure and Tekla Structures.

Autodesk Revit Structure is another version of the Autodesk family. As with the other Revit programs, there is smooth interoperability between Revit Structure and other Revit programs such as Revit Architecture and Revit MEP. The addition of Robot Analysis makes Revit Structure very capable analysis software. The Robot Analysis is the extension that allows Revit Structure to perform the structural analysis of a given project. Revit Structure also focuses on the ability to create engineered beams and project-unique components. This asset gives the user the flexibility to engineer complex projects. The Revit interface for Revit Structure also improves the capacity to engage in large project files. Figure 8 below shows the interface of Revit Structures.
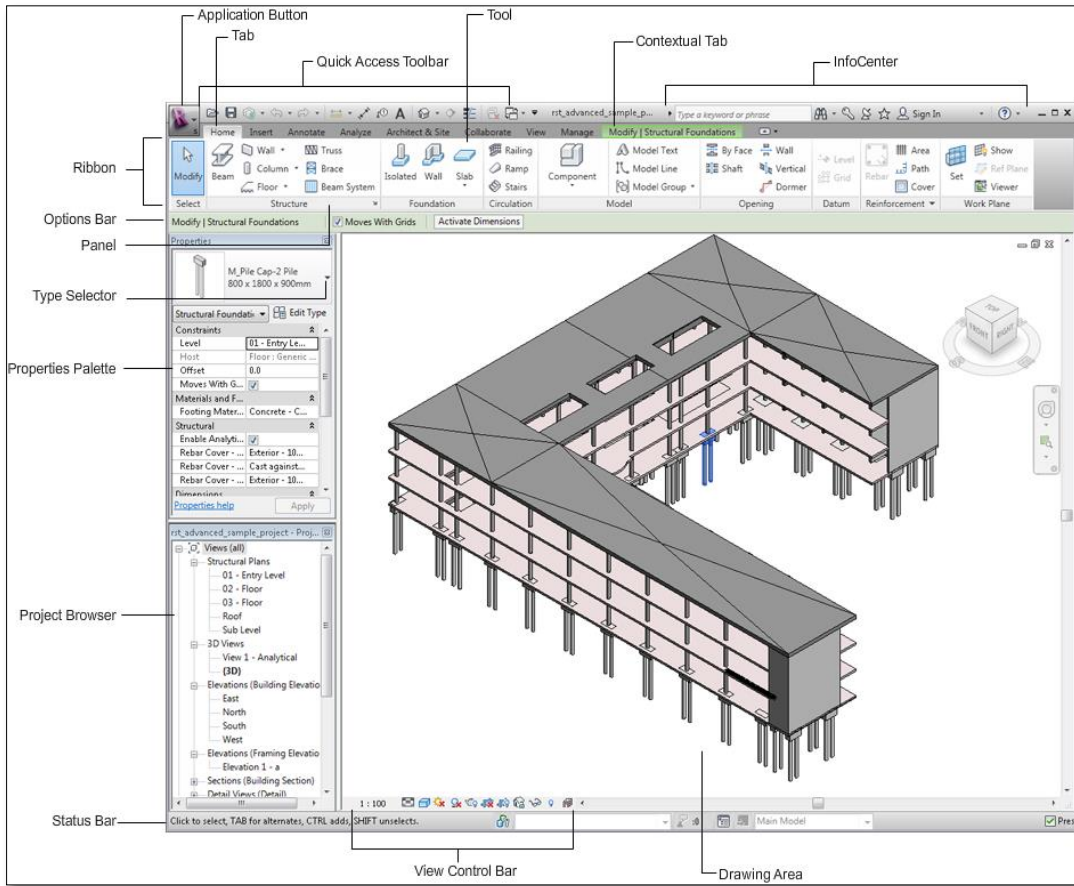
Figure 35: Revit Structure Interface (Autodesk, 2011)

Tekla Structures is another structural analysis and design software. Although it is not part of the Revit family suite, it does have extensions for interoperability with Revit models. This allows the software to work with Revit Architecture and other models of the sort. Tekla Structures also prides itself in the open BIM approach that enables users to use IFC's to work with different software programs (Tekla, 2015a). Figure 9 below shows the interface of Tekla Structures.
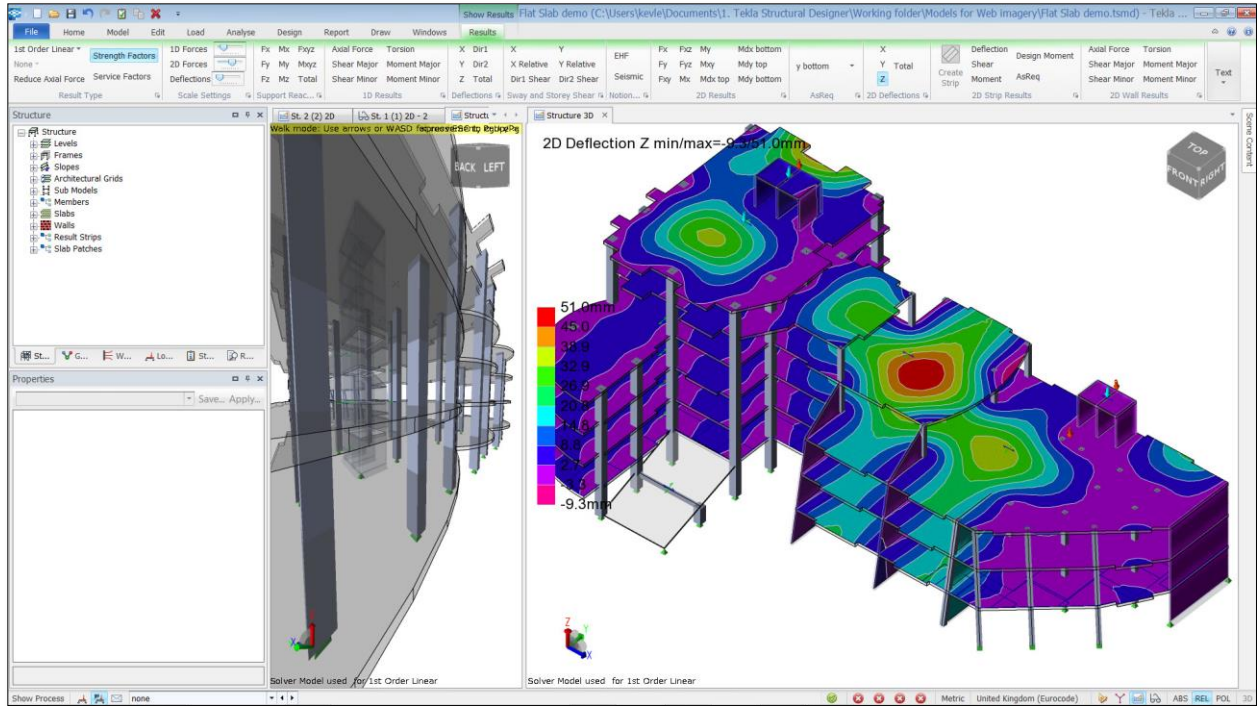
Figure 36: Tekla Structure Interface (Tekla, 2015b)

3.2.1.3 Construction

Two well-known construction software programs are Autodesk's Navisworks and the Solibri Model Checker. The main objective of the two software is to avoid construction design mistakes while assuring quality of the project. By using features such as "clash detections" in Navisworks and "code checking" in Solibri, users are empowered to not only detect possible problems, but visualize and seek solutions to these problems. Early detections empower firms to avoid problems that can cause expensive fixes and lengthened project durations.

The purpose of the Autodesk Navisworks program is to "help enable coordination, construction simulation, and whole-project analysis" (Autodesk, 2015b). The program is used to optimize scheduling, detect clashes and have constant collaboration amongst the different trades working on a project. Navisworks is also designed to be able to handle large project files and many different file formats, unlike Solibri Model Checker's need for IFC's. Figure 10 below illustrates the interface of Navisworks.
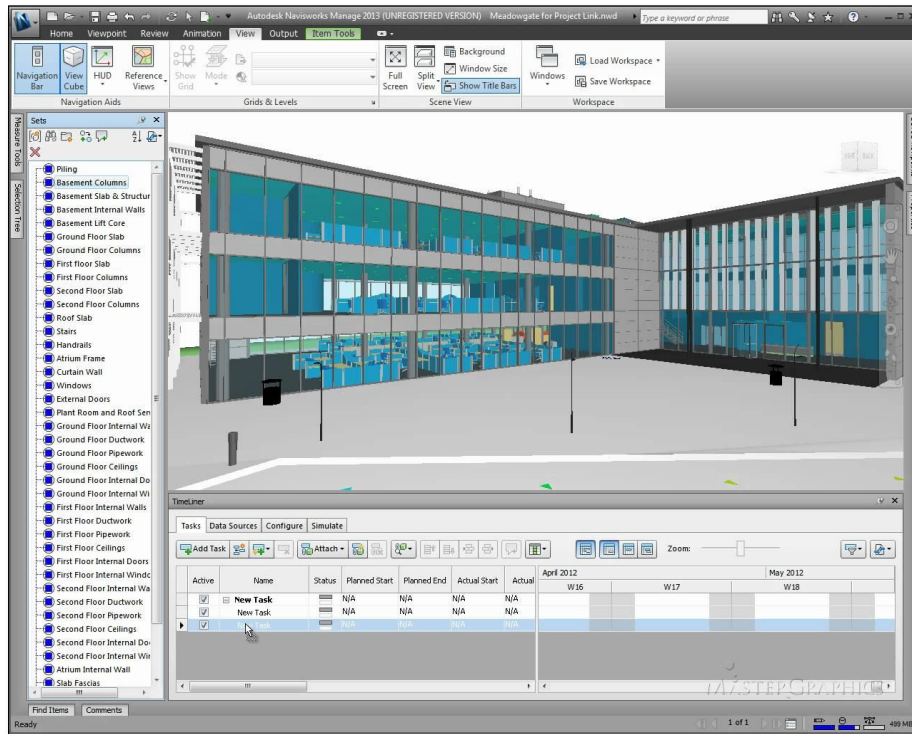
Figure 37: Navisworks Interface (Graphic Design Inc., 2012)

Solibri Model Checker allows BIM models to be checked for "potential problems, conflicts, or design code violations, and also includes visualization, walkthrough, interference detection, model comparison, and information takeoff capabilities" (Khemlani, 2012). The 2012 release of this software includes the capability to automatically select relevant tasks and rulesets. It can also provide a "result summary" for an overview of where most issues can be found. Another useful addition is the ability to customize rules and code check the structure with any new set of rules. In respects to interoperability, Solibri Code Checker can support COBie data importation for visualization (Khemlani, 2012). Figure 11 below illustrates the interface of Solibri Code Checker.
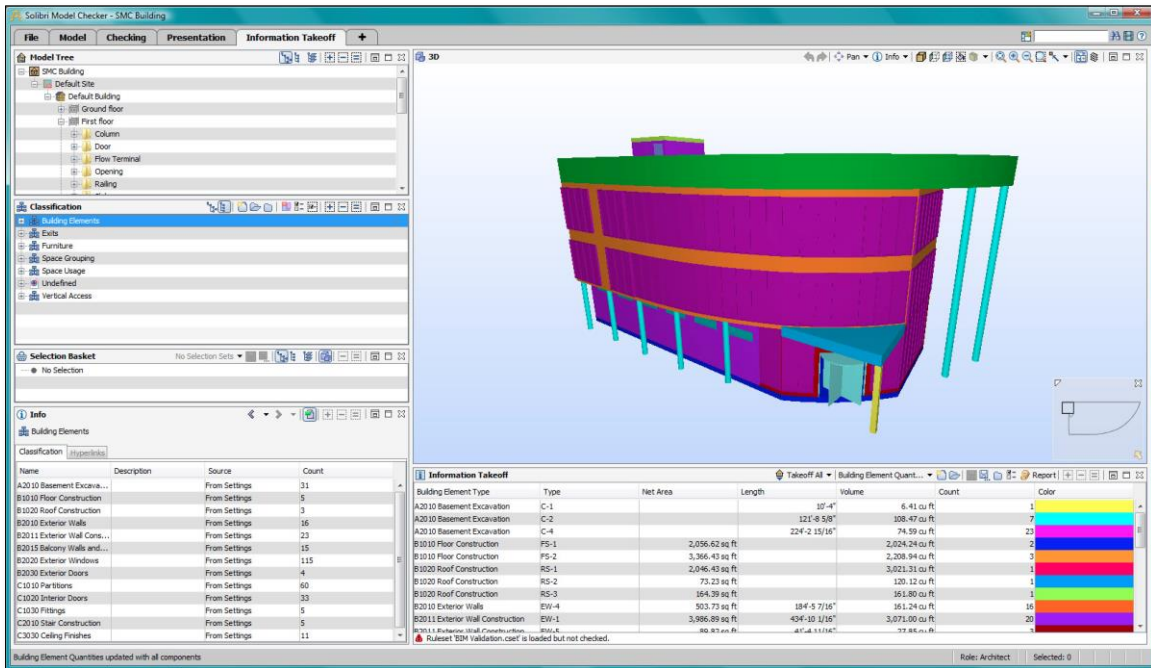
Figure 38: Solibri Code Checker Interface (Khemlani, 2012)

2.3.2 FM Software

Once a building is complete it enters into the operation and maintenance phase of its lifecycle. During this time software is employed to assure the smooth operation of the building. This includes maintenance and repairs, inventories, work orders and many more applications. Software with the purpose of operating the building is commonly referred to as Facility Management (FM) or Computerized Maintenance Management Systems (CMMS). These software programs contain the information needed for maintaining a building after completion. Many of the FM and CMMS software also have applications built into the system to efficiently access and use the information.

IBM Maximo Asset Management is very commonly used software in the field of facility management. Maximo is applied to manage all aspect of facility management processes, which include asset, work, service, contract, inventory and procurement (IBM, 2015). The software contains all the information related to the items and objects throughout the building. Maximo is a web-based CMMS program, as seen in Figure 12, which can be accessed through a computer and connected to email to send work orders.
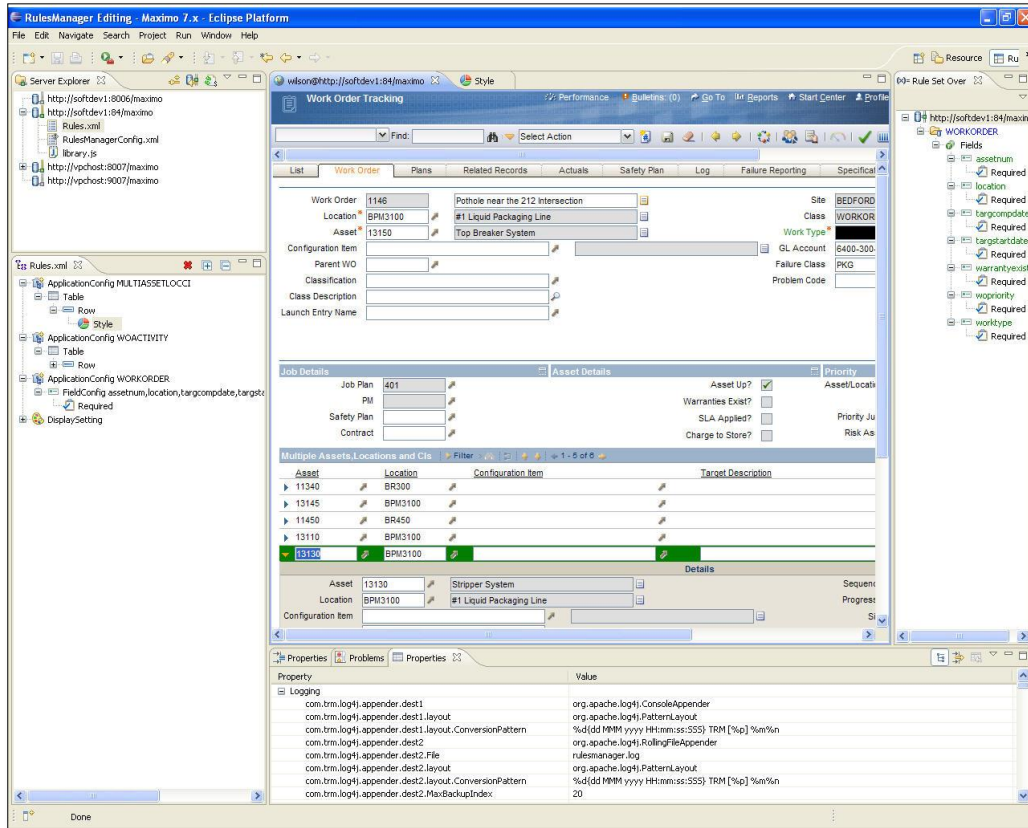
Figure 39: Maximo Interface (PRWeb, 2015)

2.3.3 Integration Software

Integrative software combines various types of software, such as BIM and FM programs mentioned above. The purpose of combining and integrating the separate programs used in a building is to assure all the information is included and it is conveniently located in a centralized location. By combining FM programs with BIM software, the details of objects are also given a location in the building through the 3D models. Examples of integrative software are EcoDomus, BIM 360 and YouBIM. Many integrators are located on the cloud so multiple copies can be investigated amongst numerous people on different devices and the information is kept synced and up to date.

2.3.3.1 EcoDomus

"EcoDomus software provides 3D view of facilities in an easy-to-use format for facility managers that links BIM with real-time facility operations data acquired via meters & sensors (Building Automation Systems, BAS) and facility management (FM) software" (EcoDomus,

2015). EcoDomus has multiple products, one of which is EcoDomus FM. This software focuses on assuring the information of the construction and design phases are accurately represented in an integrated model for the use in facility management. The program can track work orders and give a visual inventory to the user. EcoDomus is compatible with Autodesk Revit and Maximo, two extremely popular platforms, and it employs both COBie and OmniClass standards and codes (Starkov & Griffith, 2011). The software is employed to "compare "As Designed" with "As Operated" and "As Maintained" for intelligent decision making" (Starkov & Griffith, 2011). The image below in Figure 13 shows the interface and information provided in a typical window of the EcoDomus FM software.

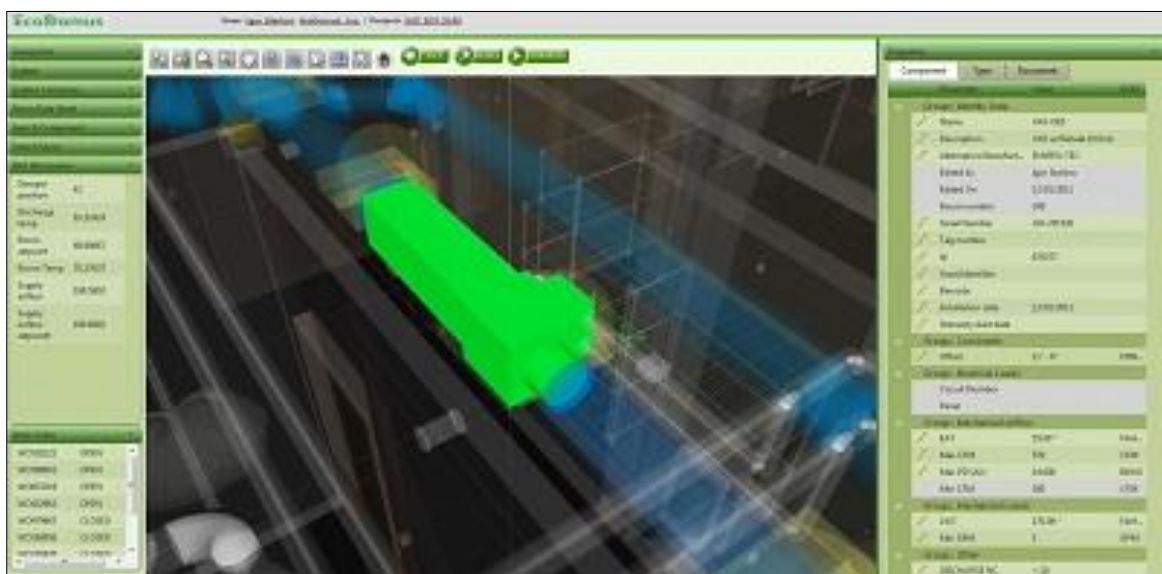**Figure 40: EcoDomus Interface (EcoDomus, 2015)**

2.3.3.2 BIM 360

BIM 360 is produced by Autodesk, and therefore has desirable compatibility with the other Autodesk products. BIM 360 is a cloud based application which can integrate various models to aid in many steps in the lifecycle of the building. The different versions of the application and the specified purposes can be viewed in Figure 14.

Figure 41: Version of BIM 360 (Autodesk, 2015c)

The application allows the user to easily access the information stored in each object simply by selecting it, and more information, such as orientation, distances and sizes, can be measured and determined in the 3D interactions. Like other integration systems, BIM 360 also provides the other views and plans of the building for gathering practical information and cross referencing details all in one software. The interface of BIM 360 can be seen on the iPad in Figure 15.

2.3.3.3 YouBIM

YouBIM is another application for integration that can be used across devices. YouBIM can connect and modify programs of a large variety from Revit, Maximo, Archibus and multiple different building management systems. YouBIM has the capabilities to show any version of the model which the user would need, whether it be the structural plans or just the HVAC systems or the layout of the lighting in a finished room. The application provides easy navigation through the 3D models and correspondences are made between 3D and 2D views to given a useful representation to the user. Each object contains all the information inputted into any of the systems for that particular item. Details such as instructions, warranties and videos can be stored and saved within the objects in their location in the model (ENGworks BIM, 2013). The program can also help the management team devise a preventative schedule and distribute work orders to allow a smooth operation. Figure 16 below displays the detailed model shown in YouBIM and the ease of access for the details of objects (ENGworks BIM, 2015).
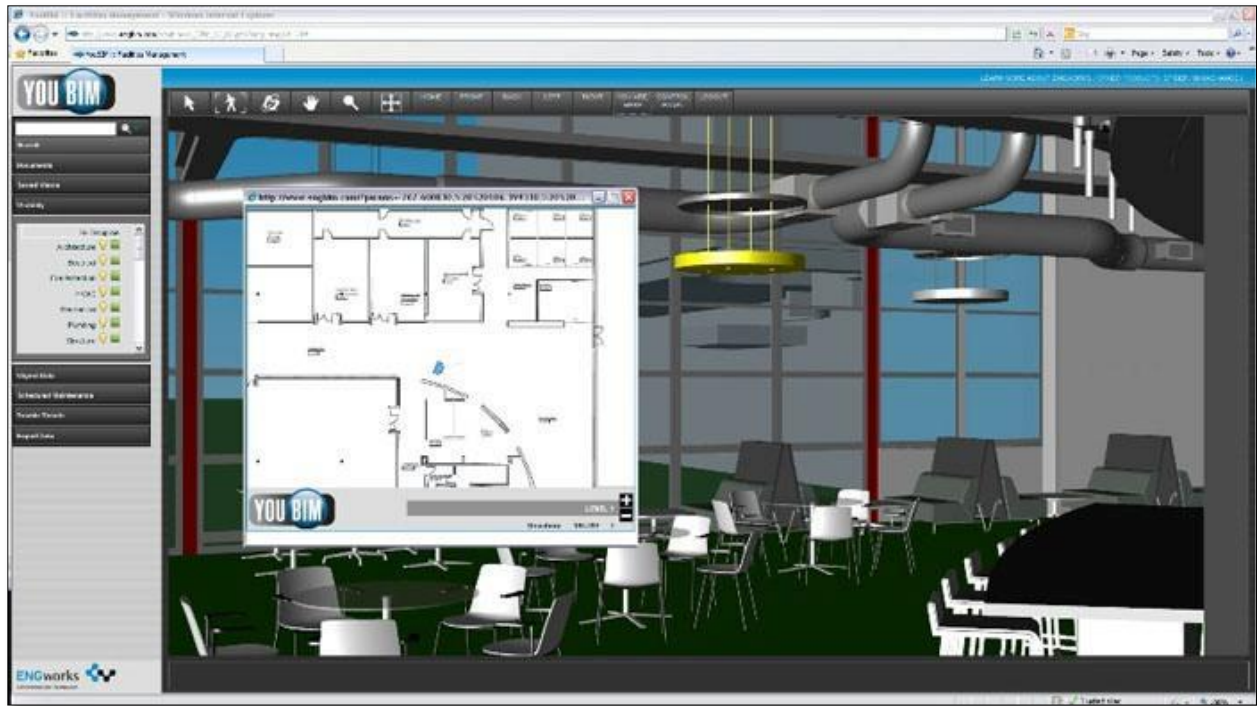
Figure 43: YouBIM Interface (ENGworks BIM, 2015)

2.4 Innovated Concepts of BIM

The use of BIM has only recently started to become common jargon in the AEC (architecture, engineering, and construction) industry. Ten years ago very few companies were partaking in the use of BIM for their projects. As previously stated, the use of BIM in the construction industry was 28% in 2008 while it grew to 71% by 2013 (Alvarez-Romero, 2014). This leads to the idea that there should always be a focus on new and innovative concepts that could take the industry to the next leap. This section focuses on three new concepts that could lead to a change in the everyday work or efficiency of the industry.

2.4.1 Augmented or Virtual Reality with BIM

Augmented or virtual reality is a new technology that is able to create a digital space of models. This allows a user to not only visualize but immerse into the model. Some virtual reality programs can even allow the user to move objects and place them in new locations. In fact, this is exactly what McCarthy Building Companies is doing currently with their projects.

For a project in the Martin Luther King Multi-Service Ambulatory Care Center, McCarthy Building used virtual reality headsets to have the doctors and nurses overview the design and location of objects in the structure. This led to specific and knowledgeable feedback on the design of the structure. Mike Oster, the vice president and CIO of McCarthy, has stated that "when we started embracing VR in the design and building process, we began seeing faster project approvals, increased positive client interactions and higher client satisfaction (Gaudiosi, 2015)." Figure 17, below, illustrates the current use of virtual reality by McCarthy Building.

Figure 44: Virtual Reality Demonstration (Gaudiosi, 2015)

2.4.2 BIM Location Services

Location services for viewing a user's position have been limited to the user's ability to navigate through a 3D model or understand their own position in regards to a 2D floor plan. With the advancement of BIM models, BIM 360 Glue has been able to develop a way of combining the two methods for locating the user. With the introduction of a 2D Map to the 3D model, there is now a dropdown option for users to easily locate themselves on a floor plan and then click a location to interact with the 3D model. This is illustrated by Figure 18 below.

Figure 45: 2D and 3D Map Locations Services on BIM 360 Glue (Walker, 2015)

2.4.3 Construction Integrated for FM

The "tsunami" effect previously discussed is an effect of BIM in the construction processes. This effect is determined by the lack of information needed for facility management and overload of information created throughout the process of construction. This recurring theme has been acknowledged as a common problem in the industry and some studies have been made to describe possible solutions.

One of these studies was performed by Sergio Alvarez-Romero in 2014. His focus was on creating an approach for a "BIM-enabled digital handover process for enhancing the operation and maintenance of the facility" (Alvarez-Romero, 2014). This was done by analyzing the current practices and information needs for the handover process. Once this was determined, Alvarez-Romero proposed "an open standard approach for the creation of a Model View Definition that combines Industry Foundation Classes (IFCs) with COBie standards or with Owner defined standards." This would allow the information, created through a construction project, to be exported into usable templates for the facility management of the structure. This would make the handover process more efficient and increase BIM usage during the lifecycle of the structure. Figure 19 below shows the example case study that Alvarez-Romero created in accordance to his approach.

Figure 46: Model with Outlined Guideline Attributes (Alvarez-Romero, 2014)

2.5 Conclusion

The BIM implementations in the AEC industry have led to more efficient, leaner projects. Although there was reluctance to this innovation from traditional construction work, the vision of technology has brought new possibilities to the workflow and accuracy of construction. With the use of different software programs, such as Revit Architecture, Bentley Hevacomp, and Tekla Structure, the industry has focused on creating better visualization and forecasting of projects for the use of the construction phase and through the lifecycle of the project. With these advancements, however, there is now a stage of uncharted territory with the many choices of software programs.

3.0 Methodology

The goal of this project is to refine and prepare Facilities Management Building Information Models to more efficiently serve the lifecycle functions for operation, maintenance and space utilization of a constructed facility. In the following section the methods are explored for the process and completion of the project. To achieve this goal the team designated three main objectives which is the foundation for this Methodology Chapter:

1. **Distinguish the necessary and unnecessary attributes included and not included in the current provided model.**
2. **Refine the current provided model to meet the requirements for the purpose of facility management.**
3. **Prepare the modified model for integration software to improve for facility management use.**

3.1 Evaluate Facility Management and Model

The first main objective is to distinguish the necessary and unnecessary attributes included and not included in the current provided model. The first portion needing completion for this objective is continued research. The team will have to determine the current state of facility management at Massport and the status of the model provided for the purpose of the project. The second part of this first objective will be to decide what information in the handover model is not needed for facility management and to identify which FM attributes are already incorporated in the model.

3.1.1 Determine current status

Entering the second term of the project the team will continue the research based in the field of facility management. Topics such as the processes and important items to consider for operating the building will be researched. Facility management practices in general and their relation to BIM will both be investigated. Through continued inquiries, the team will gain knowledge of the steps to operating a building, the workflow of a facility management system and the time consuming aspects. After studying the general concepts of management, the

connection and incorporation of BIM will be looked into. The team will search for similar scenarios where the integration of BIM, or just FM systems, improved the efficiency of the maintenance and operation of the building.

The team will interact with personnel at Logan Airport and Massport to gain insight into the current means of facility management and the future goals at Logan Airport. Interviews and visits will be held with designated people whom will have valuable input into the refinement and use of the model, and people who will be interacting with the model itself. Other stakeholders such as the sponsors, advisors and other professionals in the field will be interviewed as well. The team will devise questions and topics before the specified meeting times to assure that the interviews are dynamic, efficient and valuable.

Throughout the correspondence with Massport the team will be receiving the model. This model will be the one in which the project and all objectives will be based around. The team will investigate and interrogate the preliminary model from Massport. Information such as what program it was created and modified in will have to be discovered for consideration of future edits. Also, details such as when it was created, by whom, and for what purposes will be noted. Based on the results from the initial model examination, the team will adjust the objective, goals and methods to match accordingly.

3.1.2 Identify FM information in model

After determining the important aspects of facility management and the details of the model provided, the team can distinguish the necessary and unnecessary attributes included and not included. Information from the construction and design phases which are not needed for the facility management phase will have to be identified for elimination. For information additions, the attributes crucial for facility management will have to be designated; the team will have to investigate to find which of the attributes are already included in the model and which must be added.

To determine what should be in the model for the purpose of facility management, the team will have to gain the perspective of management. Through this perspective, details of importance and "unnecessary" details can be determined. With the newfound insight, the team will examine the model to evaluate the importance of the information in relation to the operations of facility management. If certain details included in the handover model are

identified as not needed for the next phase, it will be labeled as a possible category to eliminate from the model. Furthermore, the knowledge obtained about the processes and needs of facility management will also aid the team in deciding what to keep and what to add. The team has been provided with a list of desired objects and their identifying attributes in a excel format from Massport. These attributes will be checked for in the current model. If they are located, then they will remain and be assured for accuracy. However, if a desired object or attribute is not located in the model it will have to be incorporated by the team.

3.2 Refine Model for Facility Management

The second objective of the project, to refine the current provided model to meet the requirements for the purpose of facility management, will be completed with the resulting knowledge of objective 1.

Based on the information found to be "unnecessary" in the handover model, the details will be trimmed down. Reviewing the provided information, needed attributes, and standards and codes, the team will be able to successfully cut information not critical for facility management without compromising the model or its effectiveness. The details which are required for facility management and are incorporated in the construction model handed over will remain and be checked for accuracy. The team will perform a thorough and efficient interrogation of the items in the model for their date, details and purposes.

Once the attributes necessary for facility management are determined, the team will need to identify which items and details are not included and add them. To do this, the team will incorporate the attributes provided in the excel spreadsheet from Massport. The information for these attributes will be collected through field surveys completed prior to the model refinement. This information surveyed is what the team will be connecting to the items and objects in the model. Throughout the process of refining, the team will assure that the adjustments to the model, items and information are suitable for the standards and codes employed by Massport and the Logan Airport.

3.3 Investigate and Prepare for Integration

The third main objective of the team will be to conduct research and prepare the modified model for integration software to improve for facility management use. The team will be focusing on different integrative programs including those from the following list: EcoDomus, YouBIM, and BIM360.

The first step to accomplishing this objective will be to research the integrative programs. This research will include case studies of other projects that have used these programs, as well as expert feedback from Massport engineers. The feedback that will be given by these experts will be carefully considered for the choosing of the program. The research will also focus on the type of file formats that are accepted by the different integrative programs. The use of COBie, IFC's, and OmniClass standards will be reviewed. This review will aid in creating information that can be used in different kinds of software programs.

With the researched information, the team will be able to compare the integrative software programs. This comparison will be based off criteria such as: benefits, capabilities, and facility management team opinions. Once the prevailing attributes of each software are identified, the most suitable software to pilot for improving facility management operations at Logan Airport will be chosen. After determining the proper software to pilot, the team will conduct in-depth research for the specified program. This research will focus on the steps to modify the case-study model for compatibility with the integrative program of choice. With the knowledge of the requirements of the integrator the team will adjust the facility management model to allow for compatibility with the program. The chosen software and adjusted model will provide the team and sponsors with the material needed to pilot integrative software for improving efficiency of facility management.

3.4 Provide Recommendations

At the conclusion of the project, the team will provide Massport with recommendations and products. The projected products of the project are a modified model with the desired attributes, research of BIM-FM integration systems, and piloted software with the prepared model. The deliverables will also be accompanied by recommendations for future uses and steps continuing the results of this project.

Based on the success and failures of the investigation of the model and refinements, the team will determine certain guidelines for future models. These guidelines and parameters will

specify what programs and software to use, and what kinds and quantity of information should be included. Theoretically, the guidelines provided by the team will allow a smooth handover process between the construction and design phase to the facility management and operations phase. Along with the guidelines for creation for the model, the team will also provide recommendations on use and practices for improved efficiency of facility management. Suggested practices could include steps of using the facility management model and workflow processes that reduce time and increase productivity.

Another recommendation that the team will present to Massport is preferable integration software. Based on the research and possible pilot studies, the team will recommend which BIM-FM integrator, if any, should be incorporated into the processes of the facility management at Logan Airport. This recommendation will be determined from the ease of use, cost, capabilities, overall functionality and other designated benefits.

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