Feasibility Analysis of BIM Based Information System for Facility Management at WPI

A Master Thesis
Submitted to the Faculty
Of the
Worcester Polytechnic Institute
In Partial fulfillment of the requirements for the
Degree of Masters of Science
In
Interdisciplinary Construction Project Management
By

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May 2010

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Abstract

The traditional two-dimensional (2D) delivery system in construction industry creates communication gaps among owners, architects, and contractors. These gaps exist in all phases of project, but are more evident in operation and maintenance. Owners, especially colleges, are now starting to explore and implement new methods to receive more valuable as-built information.

Building Information Modeling (BIM) is an emerging information technology that promotes a collaborative process for the Architectural, Engineering, Construction and Facilities Management (AECFM) industry; it can facilitate the exchange and interoperability of information management, and therefore could provide enhanced benefits to colleges and universities' physical plant.

The objective of this thesis is to determine the feasibility of using BIM concepts, principles and tools to support and enhance the informational needs for planning, design, procurement, construction, operation and maintenance of the physical plant of WPI.

The methodologies used in this research include literature review of previous research conducted by WPI students; case study analysis; interview with managers at Department of Facilities, review other universities and owners' experience with BIM, and the review of material documented on the subject.

The thesis provides a conceptual guideline for implementation of BIM for WPI that

can be extended to other college campuses. The proposed guideline identifies the scope of information that needs to be included in the model, establishes a process for identify specific ways in which the information can be managed to meet the needs of the facility management at WPI.

Acknowledgements

I would like to express the deepest appreciation to my academic advisor, Professor Guillermo Salazar, who had always providing help, advice, and guidance throughout my study at WPI.

I would like to thank my thesis committee members, Alfredo DiMauro, Liz Tomaszewski, and Laura Handler. Without the collaboration of the committee, I would not have so many great ideas in my thesis.

Thank Christopher Keegan, who had provided the model to my research. I definitely learned a lot from him in Revit and other technical issues.

I owe special thanks to Michael Lane, David Messier, and Christopher Salter. The interviews with them were quite successful; I collected enough information from them to support my research.

Thank Hongwu Yang, who provided technical supports to develop the website.

To all my families, friends, thanks for being there, thank you for your support.

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1. Introduction

The traditional construction Design-Bid-Build delivery method for Architecture, Engineering, Construction, and Facility Management (AEC/FM) industry is fragmented, and is based on traditional use of 2D information systems as well as on the use of 2D paper documents. Errors and omissions in paper documents often cause unanticipated field costs, delays and eventual lawsuits between the various parties in a project team. These problems cause friction, financial expense and delays (Chuck, et al. 2008). There has been much research and efforts done to address such problems, including new project delivery methods (e. g. Design-Build), and the cutting edge information technologies (e. g. web sites, 3D software). Though these methods have improved the timely exchange of information, they have done little to reduce the severity and frequency of conflicts caused by paper documents. (Chuck, et al. 2008)

For the traditional paper-based delivery process, the poor field productivity and non-effective information flow can explain how unnecessary waster and errors are generated. The Center for Integrated Facility Engineering (CIFE) at Stanford University has documented industry labor productivity to illustrate the poor performance of construction industry in the recent 4 decades. According the research of Paul Teicholz at CIFE, the U.S. construction field productivity had decreased by 10% from 1964 to 2004, while the non-construction productivity had increased by

150% in the same 40-year-long period. The reason for the lower productivity has not yet been clearly understood, but Chuck Eastman in the book *BIM Handbook* has concluded that the lack of industry leadership and lack of labor saving innovations would be the reasons that lower the productivity in construction industry. Sixty-five percent of construction firms consist of less than 5 people, making it difficult for them to invest in new technology (Chuck, et al. 2008). Also, due to the fragmentation of the industry, integrated information systems, better supply chain management and improved collaboration tools cannot be efficiently implemented in the construction industry. Furthermore, the use of cheap labor has stagnated the innovation of construction tools and equipment. Although some innovations have been introduced, such as nail guns, larger and more effective earth moving equipment and better cranes, the productivity improvements associated with them have not been sufficient to change overall field labor productivity (Chuck, et al. 2008).

The National Institute of Standards and Technology (NIST) performed another research study to analyze the interoperable issues of different systems and information (Eric Lamb 2009). The research showed that the inefficient interoperability accounted for an increase in construction costs by $6.12 per square footage for new construction and an increase in $0.23 per sf for operations and maintenance (O & M), resulting in a total added cost of $15.8 billion per year. Since the construction industry in an important sector of the economy of United States, the inefficient interoperability can create a large amount of waste on the nation's gross domestic product. It is considered that, Building Information Modeling, on the other hand, can reduce the waste generated from the interoperability issue and can increase the productivity as well.

Building Information Modeling (BIM) is the most recent promising development in the AEC/FM industry. The definitions of BIM are varied since different sectors of AEC/FM industry have different knowledge and needs for BIM. The NIBS (National Institute of Building Sciences) thought of BIM as a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition (National Institute of Building Sciences 2007). The ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) defined BIM as the process of using intelligent graphic and data modeling software to create optimized and integrated building design solutions (ASHRAE 2009). BIM encompasses the use of three-dimensional, real-time, intelligent and dynamic modeling, and can be a valuable tool in facilitating successful coordination and collaboration. (Holness 2008)

According to the survey of BIM Smart Market Report in 2008 (McGraw Hill Construction 2009), over 50% of each segment of architect, engineers, contractors, and owners are utilizing BIM tools at moderate levels or higher. Architects are the heaviest users of BIM and contractors are the lightest use of BIM. BIM usage is growing rapidly; nearly half of all BIM adopters use BIM in 2009, 10% higher than in 2008. (McGraw Hill Construction 2009)

Owners and facility managers can utilize BIM on new projects, renovations, and maintenance & operations. For the new projects and renovations, the owner can use building information model to shorten project schedule and obtain reliable estimates; for the facility maintenance and operations, the owner can use the as built building information model as the database for facilities & equipment (e. g. steam system, water system), space information, inspection, schedules, and commissioning. Currently, the research on how BIM can benefit the owner of colleges and universities is not an extensive compared to the documented benefits of BIM for designers and contractors.

The thesis provides a conceptual guideline for implementation of BIM for WPI that can be extended to other college campuses. The proposed guideline addresses three basic problems, what to be included into BIM, how to generate BIM, and what to do with BIM. The guideline is based on previous research conducted by WPI students, interviews with key staff at Department of Facilities, in-depth case study analysis and on the knowledge gained from experience of other universities and industry, as well as the review of material documented on the subject.

2. Background

This chapter reviews the development of BIM in industrial sector, universities and WPI, as well as an introduction to BIM tools.

2.1 BIM tools

BIM is now considered in two ways, one is Building Information Model, which is digital building model containing parametric information, and the other is Building Information Modeling, which is a concept and philosophy of a process that uses digital 3D parametric models to generate and mange the building data through its life cycle (Lee 2006).

BIM needs tools to realize the philosophy. This chapter discusses Autodesk Revit, in detail. Autodesk Revit is one of the several commercial softwares available in market today in the United States; along with ArchiCAD and Bentley. Revit has been adopted by many BIM users in AEC/FM industry and has been installed in the labs of Department of Civil Engineering.

2.1.1Autodesk Revit

General introduction

Revit is object-oriented parametric software that was first introduced by the Revit Technology Corporation in 1997 and then acquired by Autodesk in April of 2002. Revit is different from AutoCAD system since it allows the users to design with both parametric 3D modeling and 2D drafting elements. In Revit, every drawing sheet, 2D and 3D view, and schedule is an object or presentation of information from the same underlying building model database. As the user works in drawing and schedule views, Revit collects information about the building project and coordinates this information across all other representations of the project. The Revit parametric change engine automatically coordinates changes made anywhere, in model views, drawing sheets, schedules, sections, and plans (Autodesk 2009). An object in Revit is a small representation of the project. It correlates with the parametric data and the surrounding environment. For example, if the user moves a wall in the model, the windows in the wall would move together.

Interface

The interface of Revit is simple and user friendly. Revit is designed for the Microsoft Windows operating systems, the Ribbon is very similar to Windows Office, and therefore people can get familiar with Revit quickly. The users can click on the Ribbon and find the functions and commands they need, or click on the Project Browser panel to view the plans, schedules, etc. Each year, the interface changes gradually through the different versions of Revit. Figure 1 shows a screen shot of the interface of Revit 2010. The interface has been designed to make it made similar to other Autodesk Products, like Civil 3D.

Revit Parametric System

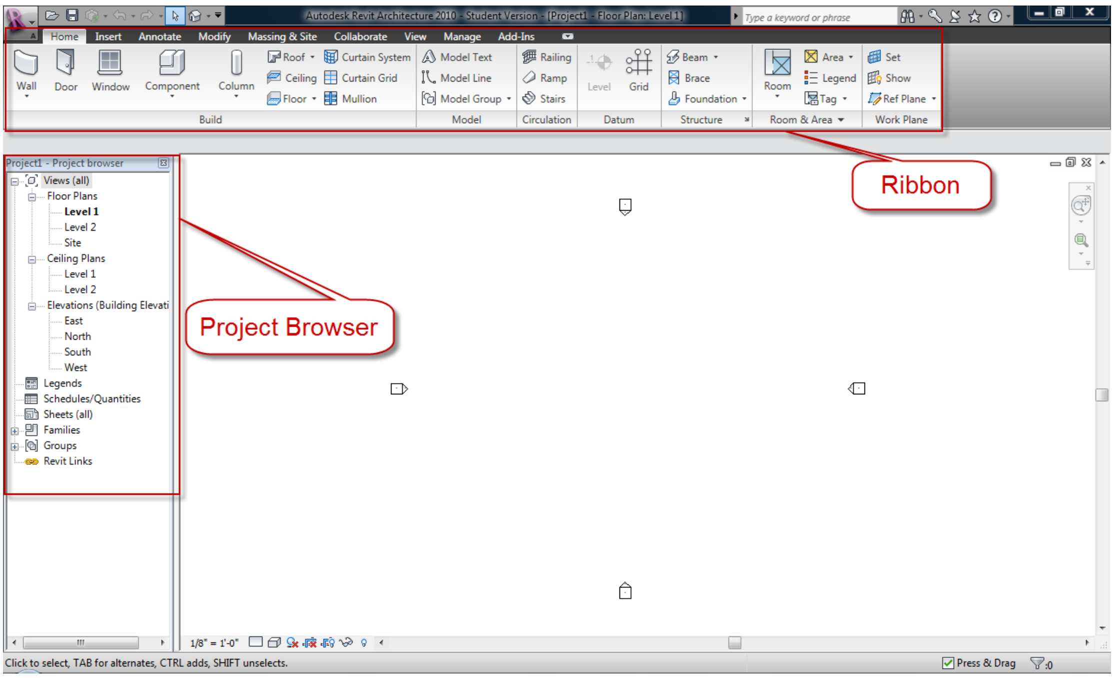
In projects, Revit uses 3 types of elements or objects: (Autodesk 2009)

➢ Model elements represent the actual 3D geometry of the building components. They are displayed in relevant views of the model. For example, walls, pipes, doors, and beams are model elements.

➢ Datum elements help to define project context. For example, grids, levels, and reference planes are datum elements.

➢ View-specific elements display only in the views in which they are placed. They help to describe or document the model. For example, dimensions, tags, and 2D detail components are view-specific elements (Figure 2)

Figure 1: The typical interface of Revit

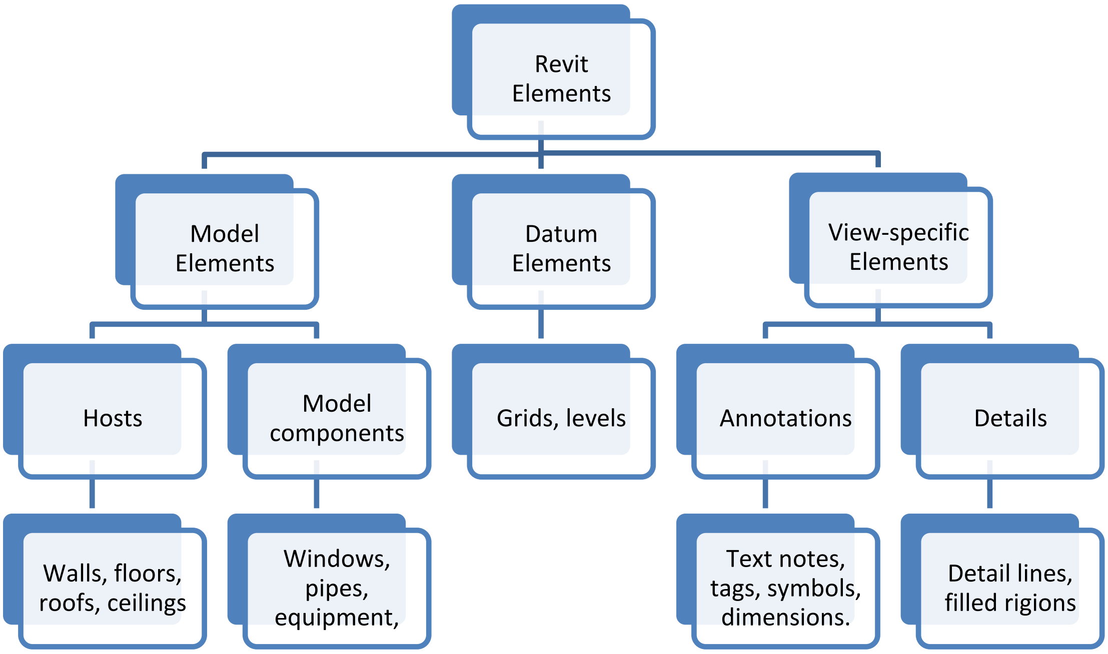


There are 2 types of model elements:

➢ Hosts (or host elements) are generally built in place at the construction site. For example, walls and roofs are hosts.

➢ Model components are all the other types of elements in the building model. For example, windows, doors, and cabinets are model components. These are hosted by host elements.

Figure 2: Revit parametric modeler (Autodesk 2009)



There are 2 types of view-specific elements:

- Annotation elements are 2D components that document the model and maintain scale on paper. For example, dimensions, tags, and keynotes are annotation elements.
- Details are 2D items that provide details about the building model in a particular view. Examples include detail lines, filled regions, and 2D detail components.

Interoperability

The IEEE (Institute of Electrical and Electronics Engineers) defined the term interoperability as the ability of two or more systems or components to exchange information and to use the information that has been exchanged. (Institute of

Electrical and Electronics Engineers 1999)

The Digital Building Lab at Georgia Tech had published the research of the interoperability of BIM tools on their websites (Georgia Institute of Technology 2009). The research results showed that Revit is interoperable with many other BIM tools, including ArchiCAD, Digital Project, FormZ, Bentley Architecture. (Georgia Institute of Technology 2009) Revit is also interoperable with other products of Autodesk, for example, AutoCAD, Civil 3D, Navisworks, etc.

Three versions of Revit: Architecture, Structure, and MEP.

Autodesk had produced Revit into three versions for the varying building design disciplines. Revit Architecture is made for architects and building designers; Revit Structure is designed for structural engineers; Revit MEP is for mechanical, electrical, and plumbing engineers. The three versions of Revit share the same interface (Figure 1) and parameter systems (Figure 2), but with different uses.

2.2 BIM in industry and universities

This part of the chapter discusses the background and development of BIM in AEC/FM industry, the BIM implementation process at different universities in the United States.

2.2.1 The development of BIM in industry

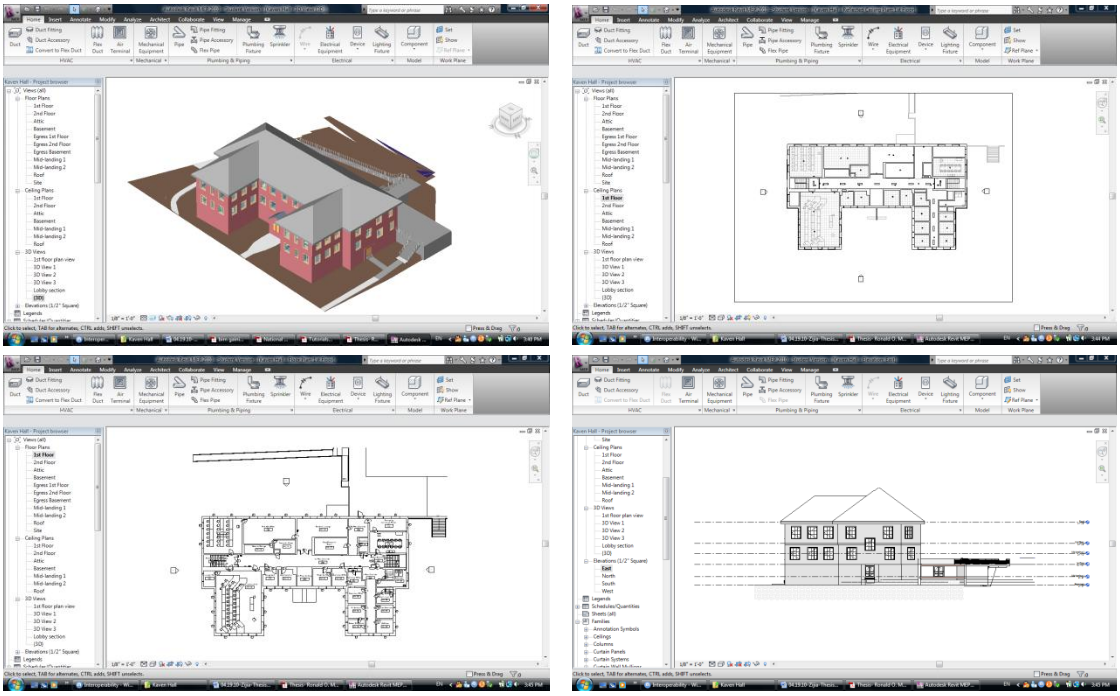
BIM is revolutionizing the AEC/FM industry by creating the ability to virtually build a project in computer. The deployment of the cutting-edge technology will bring great collaboration between all disciplines in construction projects. In the down economy, BIM had demonstrated the advantages as the users were gaining positive Return on Investment (ROI) and high productivity.

BIM is gradually being adopted in the construction industry. According to statistics from BIM Smart Market Report 2008 (McGraw Hilll Construction 2008), over 50% of each segment - architect, engineers, contractors, and owners (AEC/O) – utilized the tools at moderate levels or higher. And all BIM users plan significant increases in their use. Among the survey, architects are the heaviest users of BIM and contractors are the lightest users of BIM. BIM usage is also growing rapidly; nearly half of all current adopters (45%) in 2008 would be heavy users of BIM in 2009. (McGraw Hilll Construction 2008)

Benefits and challenges

BIM had already brought significant improvements on AEC/FM industry. The benefits of BIM are overwhelming. Overall, people recognized the advantages of BIM as 3D visualization and coordination. 3D Visualization is one of the fundamental attributes of BIM; the users can view the design elements with dimension and parameters, the model can also be viewed in 2D, section, and elevation views (Figure 3). BIM technology facilitates simultaneous work by multiple design disciplines (Chuck, et al. 2008). The coordination process shortens the design time and reduces errors and omissions. The models from all disciplines can be brought together and go through the clash detection process. The conflicts are detected in the computer before construction starts, and therefore speed the construction schedule, reduce costs and change orders. The productivity of design and construction are improved accordingly.

Figure 3: The sample 3D view, floor plan, ceiling plan, and elevation plan in Revit.



The drivers for BIM use are obvious, but users need to balance the benefits with the hurdles. In AEC/FM industry, two major hurdles had blocked the implementation of BIM. The first hurdle is that the legal responsibilities between project participants when BIM is used contractually are not clearly understood and defined. Users prefer to use BIM internally for the first several BIM projects also known as a lonely BIM approach before they have the capabilities to handle an integrated environment. For example, the architects of the new Sports and Recreation Center at WPI develop the BIM model for their internal use only, and to prepare and submit 2D drawings to contractors and the owner. In this case, the richness of information built-into the

BIM model is not exploited by all parties. However the BIM model has been shared by the architects with WPI faculty for educational purposes. The model is also being shared with the construction managers to prepare 3D visual displays illustrating site logistics.

The second problem lies with the need to train professionals in how to use these programs. BIM programs are complex, and professionals often don't have the time required to implement new software solutions. In addition, the new programs have created a need for a master builder operator--someone who has intimate knowledge of how buildings are built--but few exist (Goldberg 2005).

BIM for facility management

Owners start gaining interest in using BIM for facility management. Indiana University and Pennsylvania State University are two higher level education institutions who have taken the lead in exploring and implementing BIM. They have published their own BIM standards or Guidelines. DCAM (Division of Capital Asset Management) is a state agency responsible for major public building construction and real estate services for the Commonwealth of Massachusetts. The agency has implemented some BIM applications for several public schools, Fitchburg State College and Worcester State College. The uses of BIM for the schools were primarily focused on space planning and structure and MEP coordination. Sandia National Laboratories is a science-based lab that supports the security of United States (http://www.sandia.gov/index.html). Staff at Sandia gave an online presentation in conjunction with BIMForum in February 12, 2010. The presentation briefly introduced their understanding in BIM and the potential uses of BIM for operation and maintenance. Interestingly, Sandia was endeavored to find a solution of the interoperability issue between Maximo and Revit. Maximo is a facility management program and used by WPI as well. So Sandia may share experience with WPI in the future in this regard.

"Lonely BIM, Social BIM and Hollywood BIM"

The key concept of BIM is based upon communication and coordination of effects among all parties involved within the design and construction process. BIM is practiced in many different communication contexts. These have been informally called Lonely BIM, Social BIM and Hollywood BIM.

"Lonely BIM" – BIM is used by one firm for internal use only, it typically happens at the stage that organizations are just beginning to use the BIM techniques. This is more of a learning process stage allowing project owners to incorporate BIM concepts on one member of a project (Contractors Center Point 2010).

"Social BIM" – BIM in an environment where users would be sharing models with external partners. When the user has accumulated enough experience on lonely BIM, social BIM can provide better communication and improves productivity.

Hollywood BIM – BIM produced views look really nice or is used to win a job, but functionally doesn't help the project or process after this objective has been accomplished. For example, a beautifully rendered logistics plan, showing cranes whirling around in circles are very helpful to communicate a site logistics plan to an owner but in many cases the superintendant and subcontractors never see it or use it (Handler 2009).

2.2.2 BIM at WPI

WPI is becoming aware of the potential usefulness of BIM and has an interest in exploring in which ways BIM can be used to address the short and long term needs for collecting, storing and managing information about its physical plant. Previous work by students has been conducted to this date have shown the potential of BIM. For example, in 2005, Vireen Samdadia created a 3 dimensional parametric building model with geographic information system for WPI facility planning and management, coordinated with other undergraduate project work and developed some preliminary BIM models of different campus buildings, the purpose of these research is to set up a database to better integrate the decision making process; in 2006, Ronald Mendez built up an online information system and uploaded Revit model, submittals, warranty information, and floor plans of James Bartlett Center to illustrate the feasibility of using BIM as facility management procedure at WPI; also, Andrew Mills and Sibora Halilaj's IQP provided a conceptual idea in building management, the IQP listed all the buildings on campus and took Goddard Hall as a sample building to identify building safety features, work order, inspection, schedules, etc.

In order to capitalize in previous work and to establish efficient discussion and communication on the future use of BIM at WPI, a small group was set up. The group members include facility management department staff, faculty and students, and a BIM consultant. The group meetings were held regularly between September 2009 and April, 2010. The topics of the meetings mainly covered the general status of BIM in industry, the development of BIM at other universities, and evaluate what WPI needs to be done in the near future. WPI also set up a graduate level BIM course, taught by Professor Salazar and offered for the first time in the Spring 2010. The purpose of the course is to provide an understanding in BIM concept, and to get familiar with BIM tools (Revit Architecture).

2.2.3 BIM at other Universities

Peer universities' experience can be an invaluable asset for the development of BIM at WPI. By the end of March, 2010, two universities have implemented their own BIM guidelines, Indiana University and Pennsylvania State University. Even though these universities have different locations, campuses, and number of students and faculty, the facility management at college campuses serves same type of people and share similar responsibilities. The following section introduces BIM at other universities in detail.

2.2.3.1 Indiana University (IU)

Indiana University was founded in 1820 as the Indiana State Seminary and renamed the Indiana College in 1846, is a nine-campus university system in the state of Indiana. (Indiana University 2010). IU has 8,456 faculty and 107,160 students; and has 3,639 acres across 9 campuses.

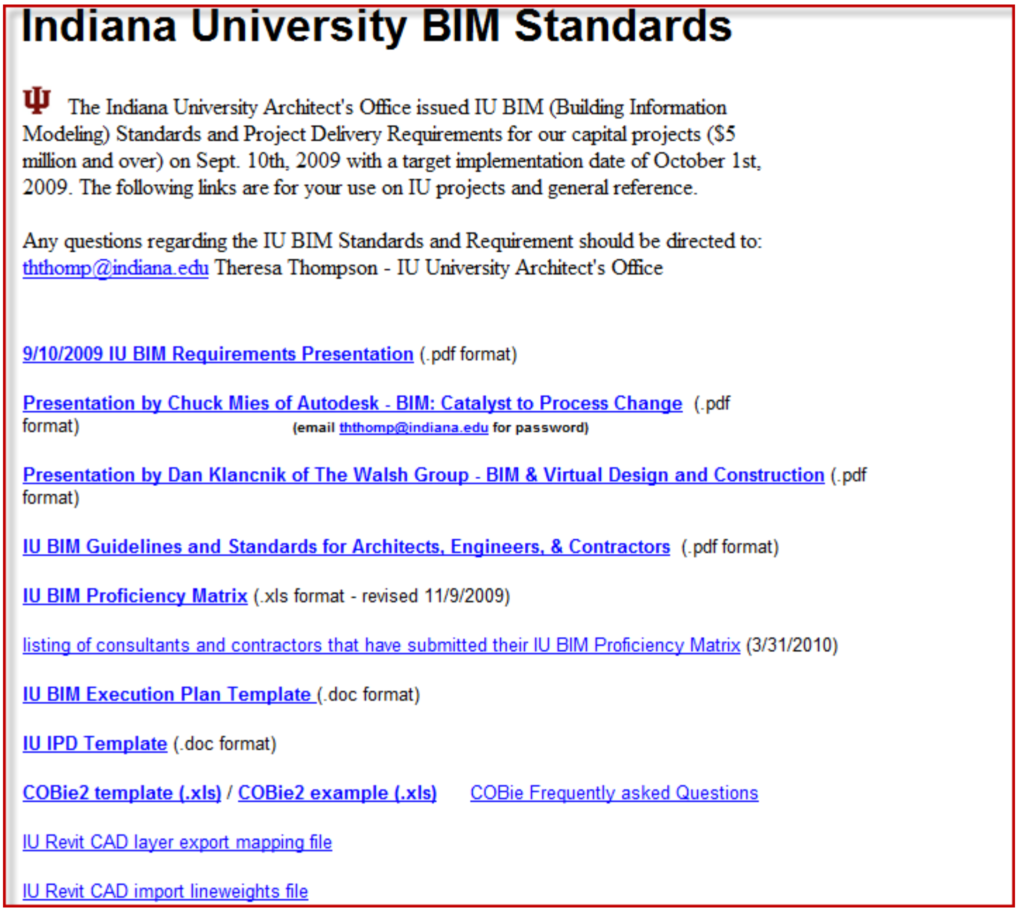
Indiana University is one of the pioneers of American universities using BIM. The research sources of BIM at IU came from the website.

The IU BIM resources website

The BIM resources of IU were collected through the website: http://www.indiana.edu/~uao/iubim.html. Figure 4 is a snapshot of the website. The website had published all the BIM documents, including BIM Guidelines and Standards, BIM Proficiency Matrix, and Execution Plan. In the future, WPI should publish her own BIM guidelines and standards to the World Wide Web.

The website is a part of IU Architect's Office; the Office, in conjunction with Engineering Service, strives to create a quality environment through planning, design and construction management of facilities for Indiana University. In support of the University's mission, they seek to enrich the education and research environment by implementing high architectural and engineering standards throughout Indiana University. (Indiana University Architect's Office 2010) The website had published all the documentations and references related to BIM use at IU. At the time of the writing, the major publications were included in Table 1.

Figure 4: Indiana University BIM website (April; 2010)



Indiana University BIM Standards

The Indiana University Architect's Office issued IU BIM (Building Information Modeling) Standards and Project Delivery Requirements for our capital projects ($5 million and over) on Sept. 10th, 2009 with a target implementation date of October 1st, 2009. The following links are for your use on IU projects and general reference.

Any questions regarding the IU BIM Standards and Requirement should be directed to: ththomp@indiana.edu Theresa Thompson - IU University Architect's Office

9/10/2009 IU BIM Requirements Presentation (.pdf format)

Presentation by Chuck Mies of Autodesk - BIM: Catalyst to Process Change (.pdf format) (email ththomp@indiana.edu for password)

Presentation by Dan Klancnik of The Walsh Group - BIM & Virtual Design and Construction (.pdf format)

IU BIM Guidelines and Standards for Architects, Engineers, & Contractors (.pdf format)

IU BIM Proficiency Matrix (.xls format - revised 11/9/2009)

listing of consultants and contractors that have submitted their IU BIM Proficiency Matrix (3/31/2010)

IU BIM Execution Plan Template (.doc format)

IU IPD Template (.doc format)

COBie2 template (.xls) / COBie2 example (.xls) COBie Frequently asked Questions

IU Revit CAD layer export mapping file

IU Revit CAD import lineweights file

Table 1: The files that had been published by IU by the end of March, 2010

File Name	Format	Date
IU BIM Guidelines and Standards for Architects, Engineers, & Contractors	.pdf	Published 9/10/2009
IU BIM Proficiency Matrix	.xls	Revised 11/9/2009
listing of consultants and contractors that have submitted their IU BIM Proficiency Matrix	.pdf	Published 3/8/2010
IU BIM Execution Plan Template	.doc	
IU IPD Template	.doc	
COBie2 template	.xls	
COBie2 example	.xls	
IU Revit CAD layer export mapping file	.txt	
IU Revit CAD import lineweights file	.txt	

IU-BIM Guidelines

The BIM Guidelines was an important document not only for the BIM at IU but also for the research of BIM at college campuses. It was issued on Sept. 10th, 2009. The BIM Guidelines mainly defined BIM roles and responsibilities of all the project participants (owners, designers, engineers, contractors, O&M managers) in the project processes, from pre-design to commissioning. The BIM Guidelines applied to IU A/E selections advertised on or after October first, 2009 for the projects with total funding of $5M or greater. (Indiana University Architect's Office 2009)

The BIM Guidelines had five major components: Chapter 1 (Requirements) defines software requirements. The deliverable file format for all BIM project models is to be .RVT (Autodesk Revit). Other software, include civil, geo-referenced, and collaboration software must be interoperable with Autodesk Revit.; Chapter 2 (Process) defines the submission process of two other important documents- *BIM Execution Plan* and *IPD Methodology Plan*, the chapter also defines and identifies model quality, energy requirements and design deliverable schedule and milestones, from conceptual phase to construction documents; Chapter 3 (Objectives and Application) defines the detailed BIM requirements for each project phase, from Pre-Design to Commissioning. Each phase has subcategories such as general, energy requirements, deliverables. Along with the BIM requirements, the Guidelines establishes the methods as to how BIM is being transferred from the project beginning to the ending; Chapter 4 (Ownership and Rights of Data) claimed the ownership of all CAD files, BIM files, and Facility Data belonged to IU; Chapter 5 (Terminology) is a list of terminologies that would occur during the projects and in the documentations.

BIM Execution Plan

The intent of this BIM Execution Plan is to provide a framework that will let the owner, architect, engineers, and construction manager deploy building information modeling (BIM) technology and best practices on this project faster and more cost-effectively. This plan delineates roles and responsibilities of each party, the detail and scope of information to be shared, relevant business processes and supporting software. (Indiana University Architect's Office 2009)

The BIM Execution Plan shall be submitted to Indiana University by the design team within thirty (30) days of contract award (Figure 5). The BIM Execution Plan will be reviewed and approved by Indiana University within fourteen (14) days after

Figure 5: BIM Execution Plan and IPD Methodology Plan submission process

the submitting of the BIM Execution Plan (Indiana University Architect's Office 2009). The BIM Execution Plan identified roles and responsibilities of project participant in a BIM environment.

IU IPD (Integrated Project Delivery) Methodology Plan

The IPD Methodology Plan shall be submitted to Indiana University within thirty (30) days of contract award (Figure 5). The IPD Methodology Plan will be reviewed and approved by Indiana University within fourteen (14) days after the submitting of the IPD Methodology Plan. The IPD Methodology Plan shall demonstrate a high level of integrated design while identifying project team members and how they will interact with each other during the project. This plan will include a critical path methodology on modeling procedures and model information validation. Examples of IPD Methodology plans are, but are not limited to, Reverse Phase Scheduling and Critical Path Modeling. The IPD Methodology Plan will be a part of the final bid documents.

The template of IPD Methodology Plan is drafted by IU's architect's office. The intent of the plan is to formalize a desire to see higher levels of integration within the design and construction process than traditional methods.

IU BIM Proficiency Matrix

The BIM Proficiency Matrix is a matrix that was designed to measure the expertise of a firm as it relates to using a BIM process on projects. It is used as one of the many selection criteria during the selection process.

The Matrix is implemented using a spreadsheet file (see appendix B) and contained eight selection categories (A-Physical Accuracy of Model; B-IPD Methodology; C-Calculation Mentality; D -Location Awareness; E-Content Creation; F-Construction Data; G-As-Built Modeling; H- FM Data Richness), each category has four parameters. The total score of BIM Proficiency Matrix can be achieved is 32. IU had defined 5 levels of BIM standards based on the scores submitted by firms, the top level is "ideal", scoring 29-32; the bottom level is "working towards BIM", scoring between 0-12. By March 19, 2010; 24 firms had submitted their Proficiency Matrix to IU (see appendix C).

2.2.3.2 Pennsylvania State University

Pennsylvania State University (PSU) published BIM Project Execution Planning Guide Version 1.0 (hereinafter referred to as the "Guide") on October 8th, 2009. The Guide was developed by the Computer Integrated Construction Research Program at the PSU, and was sponsored by funding institutions such as The Charles Pankow, and the Pennsylvania State University Office of Physical Plant.

The document provides development of a BIM Project Execution Plan by PSU. The purpose of BIM Project Execution Plan is to ensure that all parties are clearly aware of the opportunities and responsibilities associated with the incorporation of BIM into the project workflow. (Pennsylvania State University 2009)

This guide outlines a four step procedure to develop a detailed BIM Plan, as shown in the Figure 6 below. The procedure is designed to steer owners, program managers, and early project participants through a structured process to develop detailed, consistent plans for projects. The four steps include:

1) Identify high value BIM uses during project planning, design, construction and operational phases;

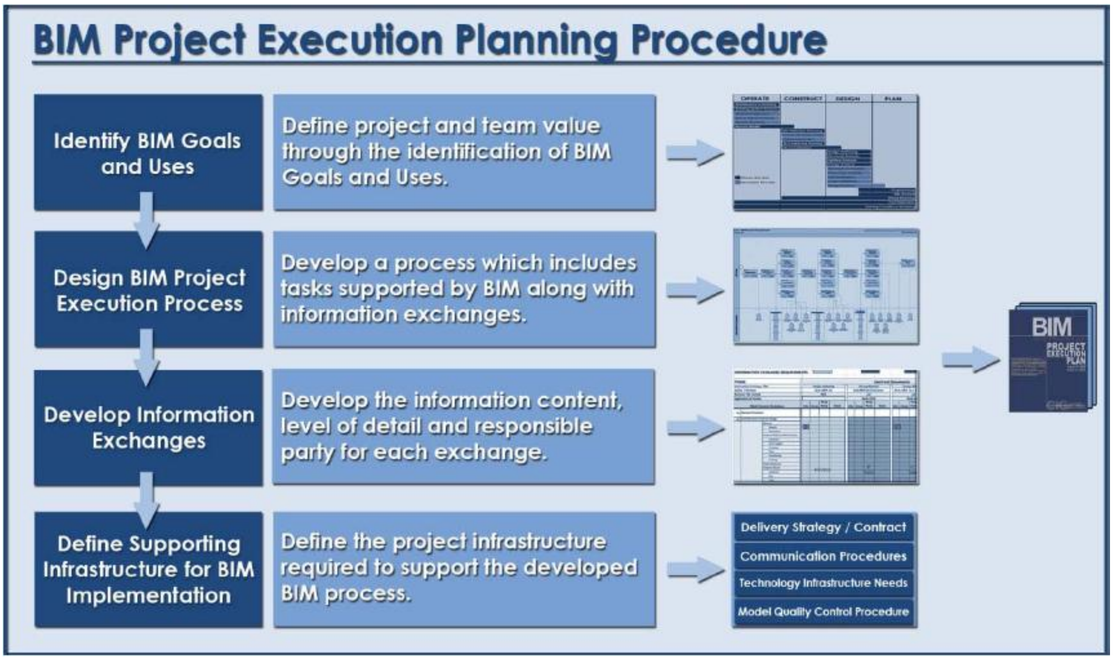
2) Design the BIM execution process by creating process maps;

3) Define the BIM deliverables in the form of information exchanges;

4) Develop the infrastructure in the form of contracts, communication procedures, technology and quality control to support the implementation (Pennsylvania State University 2009)

The first step is to identify the appropriate BIM uses based on project and team goals. Figure 7 lists twenty-five possible uses for consideration on a project. The Guide had provided a method for identifying appropriate BIM uses for a target project.

Figure 6: The BIM Project Execution Planning Procedure (Pennsylvania State University 2009)



The second step in the Guide is to design the BIM Project Execution Process, after each BIM use is identified. The Guide developed a procedure to design the BIM Project Execution Process. The process map developed in this step allows the team to understand the overall BIM process, identify the information exchanges that will be shared between multiple parties, and clearly define the various processes to be performed for the identified BIM Uses. (Pennsylvania State University 2009)

After the process map has been developed, the next step would be defining the requirements for information exchanges. The Guide presented a method for defining information exchange. In order to accomplish the tasks, an Information Exchange Worksheet was designed.

The final step in the Guide is to identify and define the project infrastructure for the BIM Project Execution Plan. Nine categories were listed to support the infrastructure, as is shown in the figure below.

Figure 7: BIM Uses throughout a Building Lifecycle (Pennsylvania State University 2009)

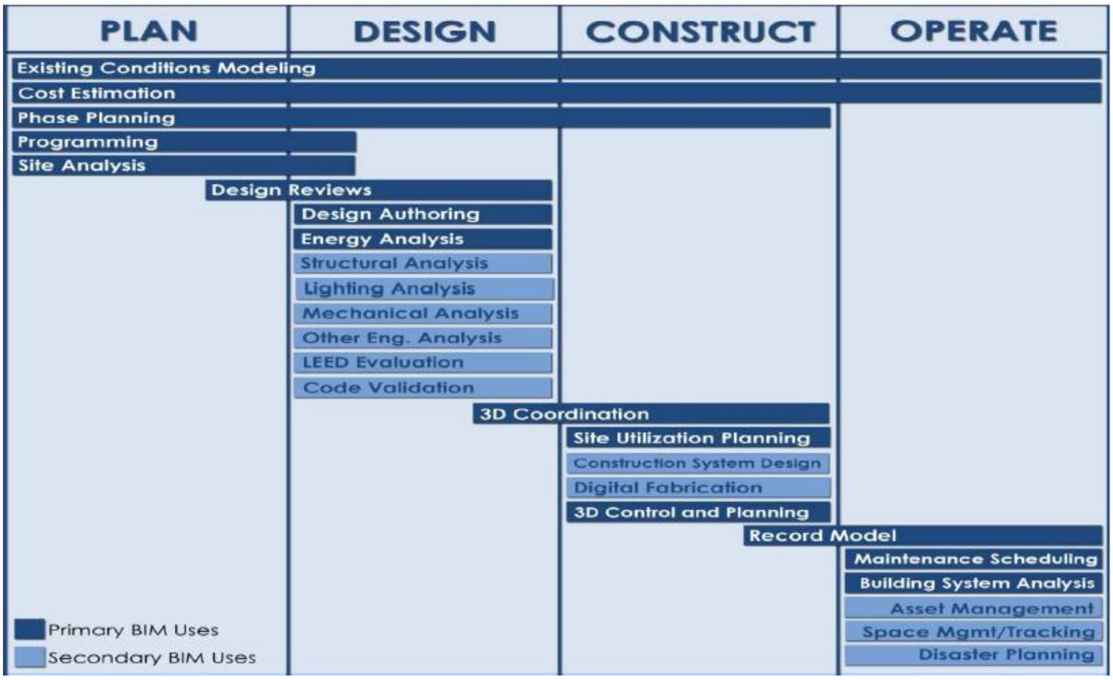


Figure 8: BIM Project Execution Plan Categories

2.2.3.3 What WPI can learn from IU and PSU

Table 2: The differences between WPI, IU and PSU (Source: Wikipedia).

	WPI	IU	PSU
Type	Private	Public	Public
Faculty	324	2,965	8,626(full and part time)
Students	4,027	42,347	94,301
Campus	80 acres	1,937 acres	5,448 acres
Location	Worcester; MA	Bloomington, IN	University Park, PA
Administrative facility department	Department of Facilities	The University Architect's Office and Engineering Services	Office of Physical Plant

WPI should understand the differences among the three colleges. Table 2 compares WPI, IU and PSU in many aspects. It is easily concluded from the table that WPI is much smaller than IU and PSU, in terms of number of students and quantity of facilities. So WPI may not have as many construction activities as IU or PSU. However, WPI can still learn the concept and process of BIM implementation.

Firstly, WPI should realize the importance of standardization for implementing BIM, both IU and PSU have published very detailed guidelines for delivery strategies, model quality, organization responsibilities, etc. WPI should publish its own BIM standard eventually.

Secondly, the real project experience is very important. The detailed requirements in BIM standard (e. g. energy requirements) should be based on WPI's experience and situation. In most cases, WPI needs to collaborate with design team or contractors to define the requirements.

3. Methodology

The objective of this research is to set up a conceptual BIM guideline for facility management at WPI. The methodology used in attaining this research objective includes literature review, case study, group meeting and presentations, interviews, and previous research of WPI students.

3.1 Literature Review

In order to learn and understand the use of BIM at industry and at college campuses, a literature review was conducted. The goal of the literature review was to get an understanding of the application and research of BIM in industry and academic institutions. Also, the construction industry situation, operations and maintenance of a building were another important aspect of the literature review. The literature reviewed consisted of IQP and Master's thesis report of WPI students, white papers, journals, websites, and other industry related publications.

3.2 Case Study

The purpose of the case study is to explore and understand the details involved in implementing BIM for the facility operation and maintenance for college campuses. The case study consisted of two sections, the individual building section and inter-building system section. The Kaven Hall (http://www.wpi.edu/about/tour/kaven.html) was chosen to develop a case study of individual building based on a Revit model. The original Kaven Hall Revit model was developed by a group of WPI students through their IQP projects using 2D drawings and Revit Architecture. The model contained the architecture portions of Kaven Hall, and did not include structure and MEP part, but it is still good enough to support this research. Another reason for choosing Kaven Hall was that Kaven Hall is the home of Civil and Environmental Engineering and facility and equipment in the building can easily get accessed and updated in the future.

Autodesk Revit is the BIM tool used for developing the case study. Revit was chosen because the wide spread of applications, people in the AEC/FM industry understand it much; the computers of WPI Civil and Environmental Engineering Department has installed Revit. Other programs, included Autodesk Design Review, Google Earth, and Autodesk Civil 3D, have also been used to support the development of model.

The final Kaven Hall model consisted of two parts, the architecture part and the operation and maintenance part. The architecture of Kaven Hall was updated from the original one, which was developed by an IQP group (Halilaj and Mills 2006). The facility model was built up based upon the needs expressed by the Department of Facilities and lab manager at Kaven Hall. The information is critical to the success of the case study because users' needs from BIM is important, which means the scope and level of details of BIM should be defined prior to the implementation of BIM. Then, based on the information, the facilities and equipments were added into the model.

The methodology of developing the inter-building model was similar to Kaven Hall model. Firstly, the WPI Revit site plan was created, by importing surface from Google Earth. Secondly, based on the needs of facility management at WPI, a sample inter-building systems, including water, sewer, fire, steam systems were built up. Other building models were contributed from other WPI students; the Salisbury Labs was developed by Chris Keegan (2010), Bartlett Center model was developed by Ronald Mendez (2006).

To better determine the practicality of using the model, a BIM model viewer program was used by the end users. Autodesk Design Review is a free viewer program designed to view DWF files. The DWF files are created from the Revit file and allow users to view and navigate the model through the internet. From Design Review, users can view the same information as from Revit, but cannot modify it.

3.3 Group Meeting and presentations

In order to enable industry, WPI Department of Facilities and the academic community to have better communication and collaboration and to explore the potential use of BIM at WPI, a group was established in 2009. One purpose of the BIM group is to serve as thesis resource for the author. The BIM group members are: Guillermo Salazar, professor at WPI Department of Civil and Environmental Engineering; Alfredo DiMauro, Assistant VP for Facilities; Elizabeth Tomaszewski, Facilities Systems Manager; Laura Handler, Virtual Project Manager at Tocci Building Corporation; and Christopher Keegan, graduate student at WPI. Group meetings were set up regularly among committee members approximately every month from September 2009 to April 2010.

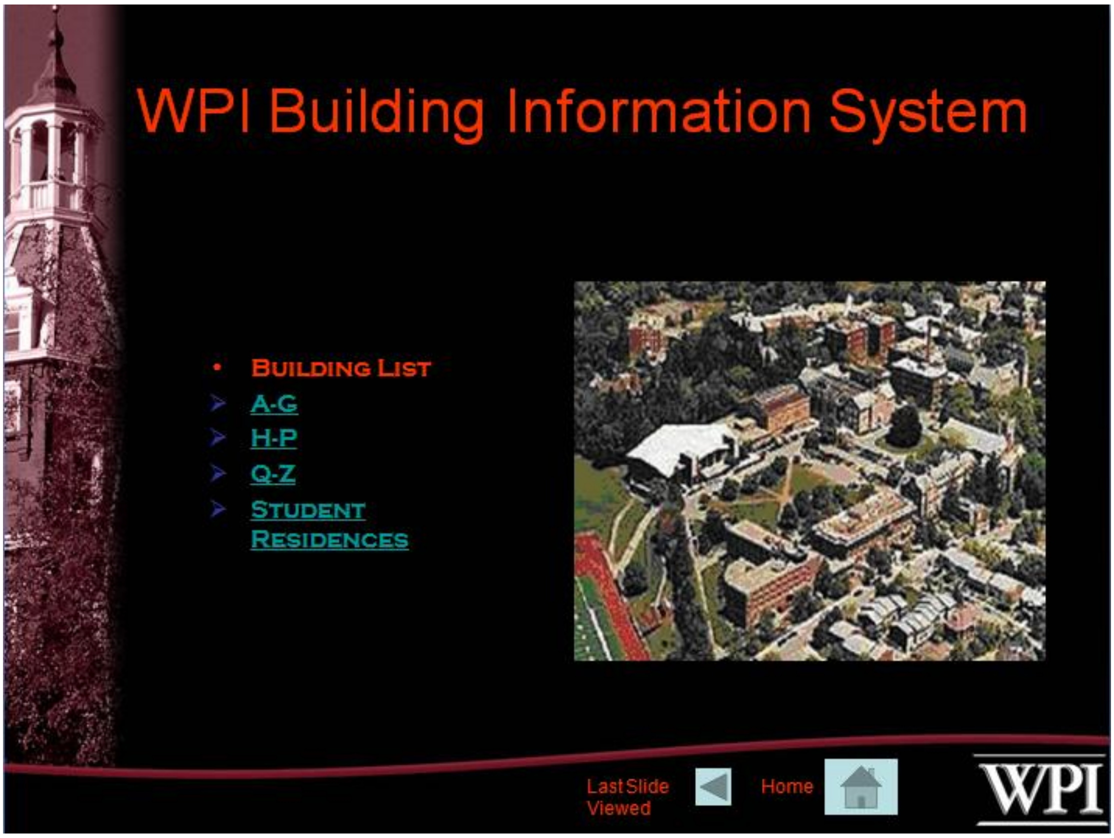
The thesis author gave a presentation in December 2009 for the Department of Facilities, to introduce the concept explored by thesis and to receive feedback from them in terms of level of interest and data needs.

3.4 Previous BIM-Related Studies at WPI

An Interactive Qualifying Project can support the thesis research, the Interactive Qualifying Project, or *IQP* as it is known on campus, is WPI's most distinctive academic requirement, and is unique in higher education. The IQP challenges students to address a problem that lies at the intersection of science or technology with social issues and human needs and is done under the direct guidance of one or more faculty advisors, usually in teams of 2-4 students. (Worcester Polytechnic Institute 2010)

The IQP used in this research was the latest IQP among the series of IQPs that were conducting research with the "e-buildings". The IQP was titled "WPI Building Information System" (Figure 9), by Sibora Halilaj and Andrew Mills and co-advised by Professor Carrera and Salazar as well as former director of WPI physical plant, Mr. John Mills. It had conceptually provided information on Goddard Hall, with the building synopsis, safety features, floor plans, work orders, and inspections were identified. The IQP project had also listed all the buildings and residential halls on campus, which would conceptually expand the knowledge and experience gained in Goddard Hall into the whole campus.

Figure 9: An IQP slide of Andrew Mills and Sibora Halilaj



The report and presentations of these IQP were reviewed, from where creative thoughts and concept were gained. For example, Sibora and Andrew's IQP identified all the building safety features for Goddard Hall (on WPI campus), and the features would be also available for other buildings. Some of the knowledge in this IQP have been used in the research.

3.5 Interviews

Four managers and directors at WPI's Department of Facilities were interviewed. They were Michael Lane, Director of Facilities Operations; David H. Messier, Manager of Environment & Occupancy; Christopher L. Salter, Director of Project Management & Engineering; and Elizabeth Tomaszewski, Facilities Systems Manager.

The interviews served to collect information and feedback about potential use of BIM and for the facility management department. Before the interview, the objectives had been set; then, the model was shown to them; and finally, ask them four simple but fundamental questions:

1. What does the model has but you do not need?
2. What does the model do not have but you need?
3. What other information do you use that could be coordinated with BIM?
4. How and who should access to the information?

In addition, the interviews served to research the current practices of information management by the Department of Facilities, among them the use of Maximo, a system used by facility management for the work order process of operation and maintenance.

4. Case Study

The objectives of the case study are to address the following fundamental issues:

- The feasibility of BIM based information system for the facility management at WPI
- Explore what should be modeled.
- Determine the appropriate level of details of the model.
- Determine how to create and manipulate the model.

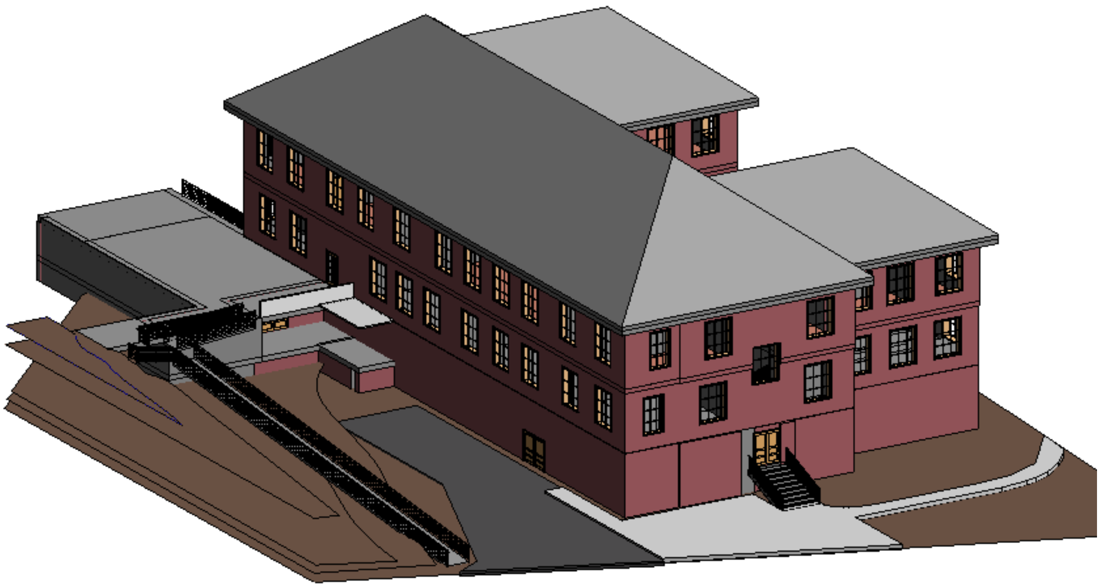
The case study for this research consists of two sections; the first section concentrates on individual building model, which is Kaven Hall. The purpose of using the individual building model is to illustrate the feasibility of using BIM for each individual building in the college campus. The proposed model should include enough information on the floor plans, elevation plans, and facilities & equipment based on the needs of the facility management department. The second section studies the inter-building systems, which are the water systems, electric systems, plumbing systems, fire systems, heating systems that connect the buildings in the campus.

The author interviewed the managers and directors at the Department of Facilities to collect information on what they need from BIM information system. Then, the author built up the model to include all the facilities and equipment based on the interviews.

4.1 The individual building section

A Kaven Hall Revit model (Figure 10) was developed to conduct the case study. The model was originally developed by a group of WPI students to fulfill their IQP (Interactive Qualified Projects) using Revit Architecture. The author chose Kaven Hall as a sample of case study for three reasons: first, the model was built very accurately and the floor plans and elevations were most updated compared to other Revit models; second, Kaven Hall is the home of Department of Civil and Environmental Engineering and therefore would be easy to get access to the information of facilities and rooms; third, the Kaven Hall is a good sample for the coordination of MEP, Fire Safety, and Environmental Safety systems.

Figure 10: Kaven Hall - Department of Civil and Environmental Engineering



The original model contained general information of floor plans and elevations, as well as the topography of surroundings; also, it contained some information of egress way and lab equipment. However, the usefulness of the information for facility management contained in the model needed to be queried. In order to make the case study more useful for the facility management, the author interviewed with several staff at the Department of Facilities, including Elizabeth Tomaszewski, Facilities Systems Manager; Christopher Salter, Director of Project Management & Engineering; David Messier, Manager of Environment & Occupancy Safety; and Michael Lane, Director of Facilities Operations. Christopher was interested in the inter-building system of water, steam and electrical. David was more concerned about the Fire Safety and Environmental Safety of WPI physical plant; he did semi-annual report of Building Safety Inspection and weekly report of WPI Hazardous Waste Storage Area Inspection. From the interview with him, the location of Chemical Fume Hood, Bio-Safety Cabinets (BSC), Emergency Showers, Wash Units, Fire Suspension systems were the most important information to have in order to conduct his work. He would like to see some related parameters like installation date, inspection date, etc. Table 3 lists the building components that have been included in Kaven Hall model. Liz and Mike, on the other hand, were interested in how BIM are connected to Maximo Work Orders. Maximo Work Order is the current system used to manage information on maintenance & operations. Figure 11 illustrates the standard work order flow; it is generated by the requester at a given building, and ends up at the office of Facility Management.

Table 3: Parameters of Kaven Hall

Architecture and site plan	Generic floor plans with room occupancy; generic ceiling plans; generic elevation plan; windows; doors; stairs; roof; surrounding site plan; furniture of some rooms
Safety features	Locations of fire extinguisher, fire alarm, smoke detector, exit sign, emergency lighting, chemical fume hood, emergency shower, inspection, and sprinkler head.
Mechanical	Location of sprinkler pump; steam; electric panel

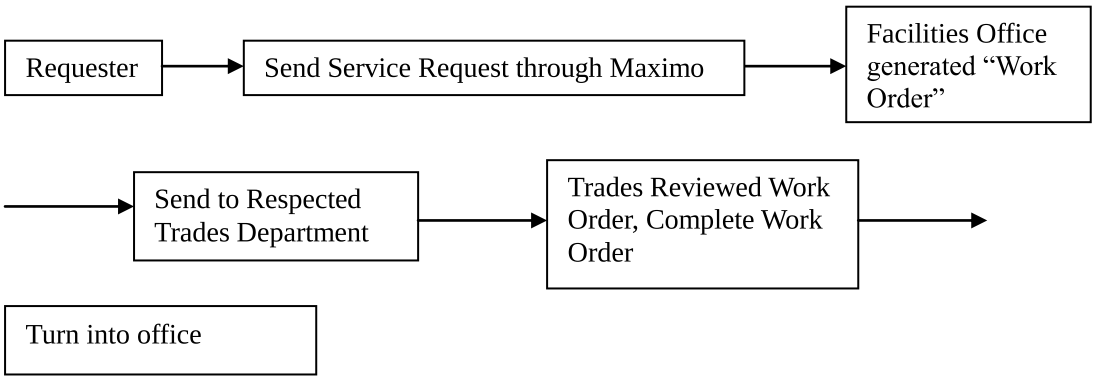


Figure 11 : Work Order Flow of WPI facility management

In order to identify the locations and parameters of those systems mentioned above, the author went around the whole building with the 2D drawings and checked the physical inventory, besides, for the private areas that the author cannot get access personally, Donald Pellegrino, the lab manager at the department helped the author to get access.

After gathering up all the information for the Kaven Hall model, the facility objects and parameters were add into the model, which the original one did not have. In order to add a new kind of object into the model, a family needed to be downloaded. In Revit, a family is a group of elements with a common set of properties, parameters and a related graphical representation. (Autodesk 2009) The same kind of elements may have different values under one family, the variations within the family called types. For instance, the Furniture family includes families and family types that you can use to create different pieces of furniture, like desks, chairs, and cabinets. The appropriate families for the model update were downloaded from the internet. Revitcity (http://www.revitcity.com/index.php) is an internet community that serves BIM users, from where the appropriate families and objects were downloaded. The locations and the types of the facilities were not 100% accurate, but roughly based on the manual drawings; so for the future work, it would be better to be provided with the accurate information. Figure 12 and Figure 13 illustrate the floor plans and ceiling plans of first floor of Kaven Hall. The ceiling plans mainly contained exit signs, emergency lights, sprinkler heads, and smoke detectors. The floor plans contained fire alarms, fire extinguishers, lab safety equipments, and mechanical equipments.

Figure 12 Ceiling Plan of first floor

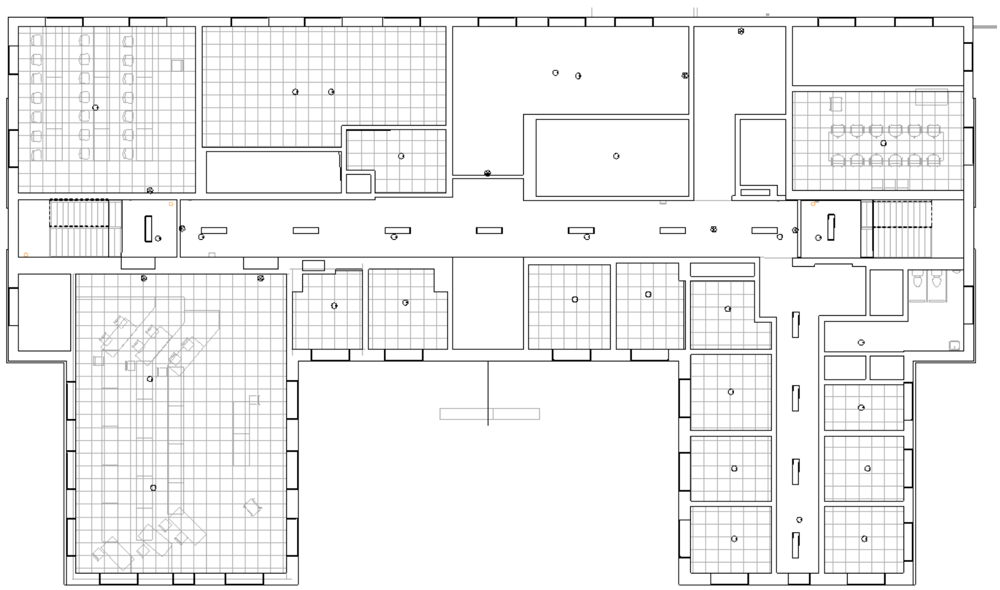
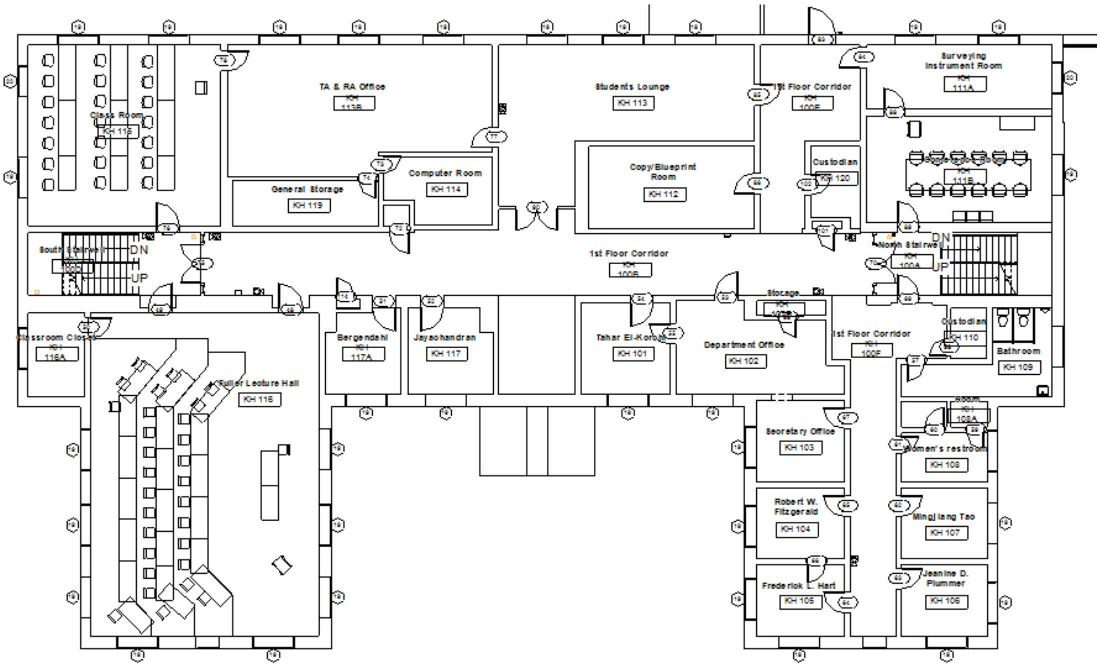


Figure 13: Floor Plan of first floor



The inter-building systems section

The reason to create a model showing the inter-building systems is totally targeted to meet the needs of the facility management department. Through the interviews with the Department of Facilities at WPI, the managers and directors were excited to see the potential uses of BIM for the systems like pipes, ducts, and wires underground, which cannot be efficiently represented in a 2D system.

The objects and elements included in the inter-building system model were Kaven Hall Revit model, Salisbury model, Goddard Hall model, campus topography surface, and sample pipes between buildings.

Figure 14 is a sample of the inter-building systems; the three buildings, Salisbury Labs, Kaven Hall, and Goddard Hall, are located in the main campus of WPI. The “lines” between the buildings are pipes underground. It is necessary to point out here that the systems provided in the model were not accurate but was made up only for illustrating on how BIM could be used for this purpose.

Figure 14: Inter-building systems

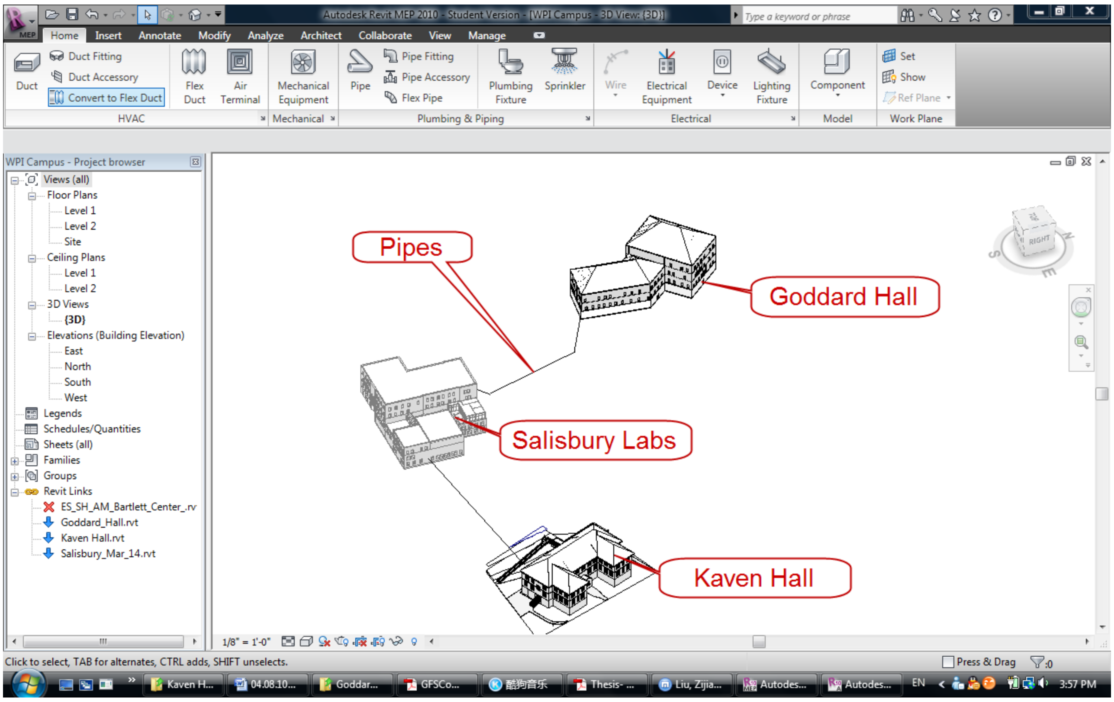
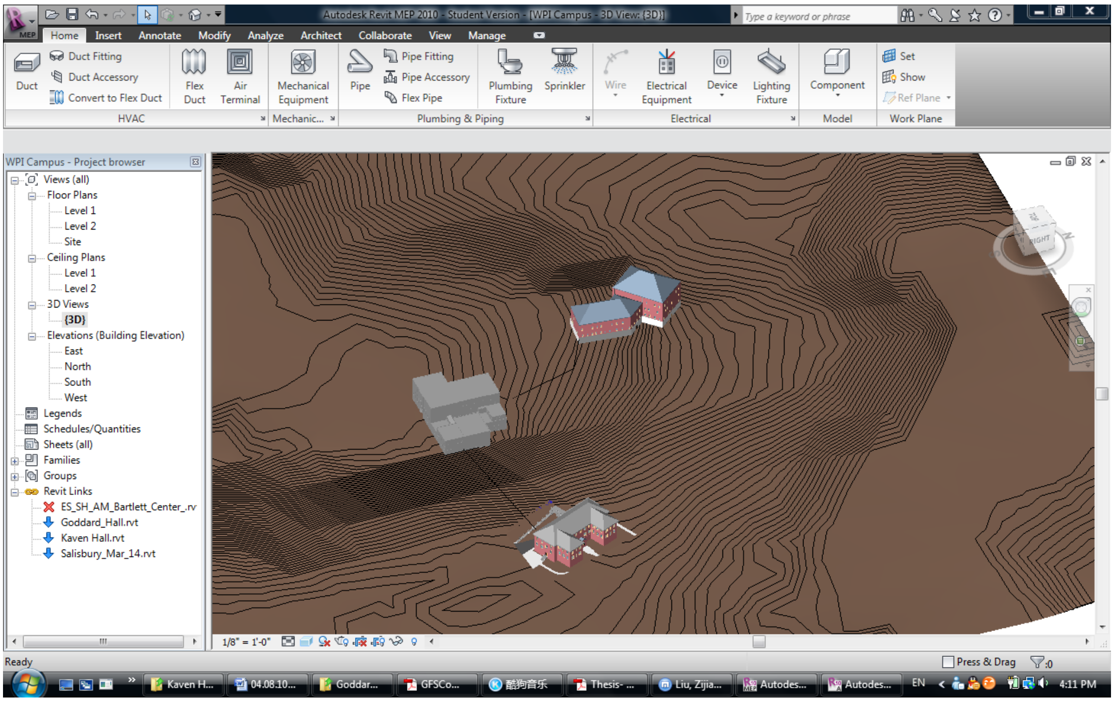


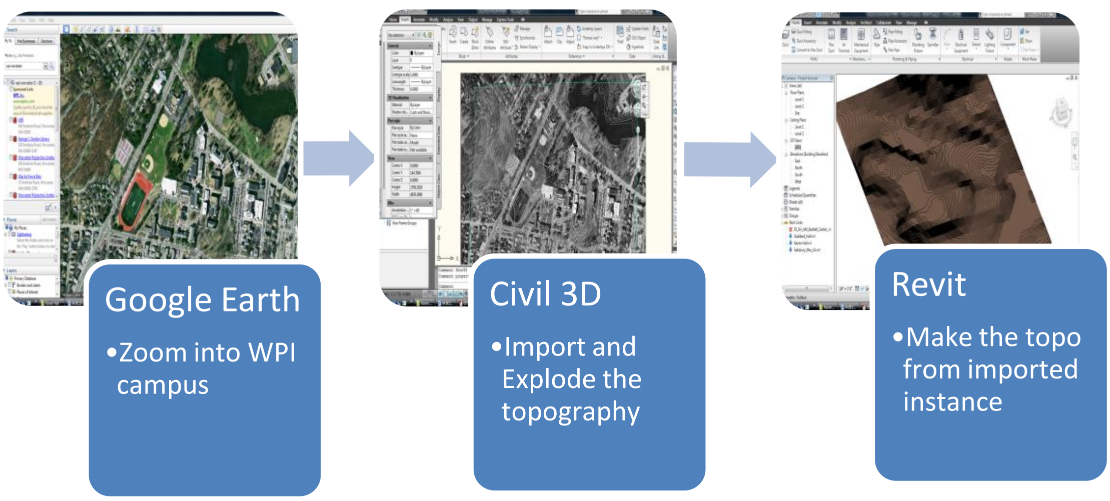
Figure 15: WPI campus topography map



The buildings actually sat on the campus map in the model (Figure 15); the brown area is the 3D WPI topography surface, which was imported directly from Google Earth. The topography was hidden in Figure 14 just for illustrating the systems clearly. The topography information is useful for the facility management. Because the buildings on the same area may "seat" on different elevations, the structure of inter-buildings systems would be influenced by the elevations and the locations of building and the depth of the location of utilities can be clearly established.

The importation of topography needs two steps (Figure 16). First, import the needed area of topography information from Google Earth into Civil 3D; second, import the exploded topography from Civil 3d into Revit.

Figure 16 Steps to import topography



To develop the inter-building systems more accurately, Revit MEP is needed. Revit MEP is a specialized version of Revit to create Mechanical, Electrical, and Plumbing systems. The reasons to use Revit MEP are obvious; Revit MEP shares the same platform with Revit Architecture, and is totally interoperable with Revit Architecture, partially interoperable with Autodesk Civil 3D and AutoCAD. Also, Revit MEP is better than Revit Architecture in terms of building up pipes, ducts, and wires.

Ideally, to build up the pipes, ducts, and wires in the model, the exact directions, connections, locations, and slopes are needed. However, in this research, the systems location does not need to be accurate. Because based on the interviews, what the facility managers would like to see is just how pipes, ducts, and wires are connected. For instance, the pipes from Goddard Hall to Kaven Hall are connected through Salisbury Labs, not directly connected (Figure 15). Additionally, the facility managers want to see some parameters of the systems, such as the diameters and materials of the pipes. The Revit system can exactly provide the information as they want. The dialogue box in the middle of Figure 17 shows the parameters of a sample pipe. The Table 4 is a list of parameters and values of the pipe from Figure 17. This has covered all aspects of parameters of a pipe, including the constraints, mechanicals, and dimensions. Therefore, the proposed inter-building system can basically satisfy the needs of the facility management for WPI, not only for the visualization purpose, but also can be an ideal database of facilities.

The systems for end users

Revit is an excellent database but not a convenient way to extract and restore information for daily use. Revit is slow of running in personal or normal computers and is very complex for those who do not have knowledge in BIM. The end users of the facility information, such as facility management and space planning, need a simpler and faster tool to convey and restore information. Autodesk Design Review can be an ideal tool for this.

Figure 17: The parameters of the pipe in Revit MEP

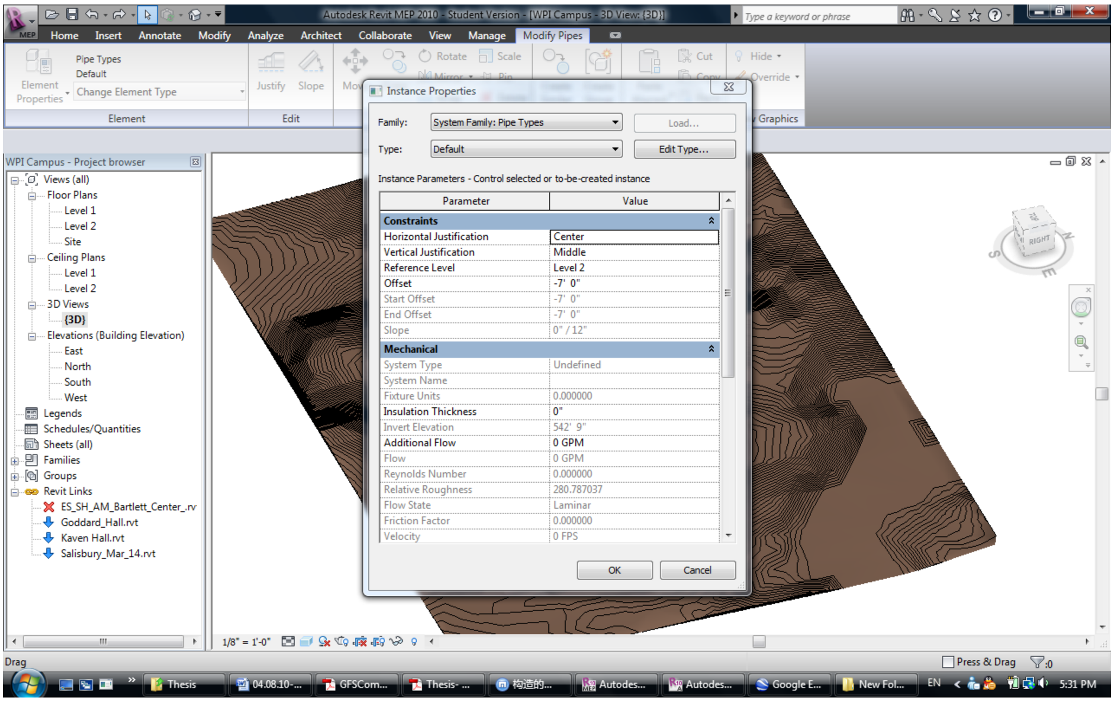
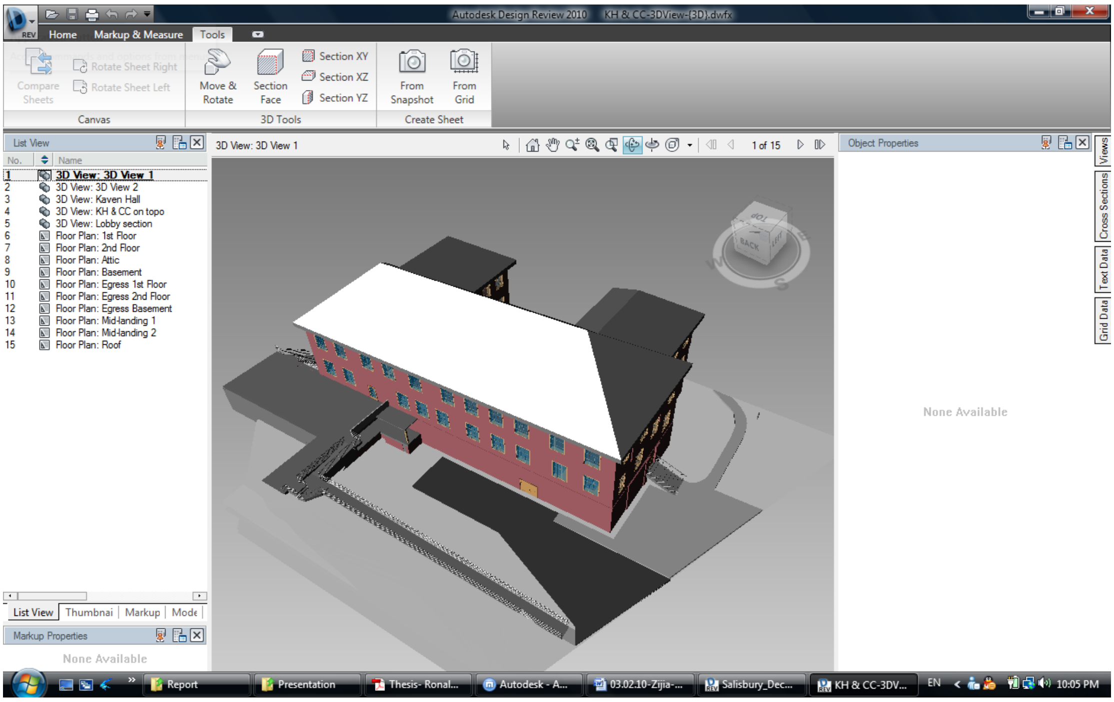


Table 4: Parameters of a sample pipe

Parameters	Value	Parameters	Value
Horizontal Justification	Center	Relative Roughness	280.787
Vertical Justification	Middle	Flow State	Laminar
Reference Level	Level 2	Friction Factor	0.00000
Offset	-7’ 0”	Velocity	0 FPS
Start Offset	-7’ 0”	Friction	0 FT/ 100Ft
End Offset	-7’ 0”	Pressure Drop	0 Psi
Slope	0” / 12”	Section	0
System Type	Undefined	Area	256.83 SF
Fixture Units	0.000000	Outer Diameter	6 5/8”
Insulation Thickness	0”	Inner Diameter	6 17/256”
Invert Elevation	542’ 9”	Size	6”
Additional Flow	0 GPM	Diameter	6”
Flow	0 GPM	Length	163’ 6”

Autodesk Design Review is one of the most popular free programs used for reviewing DWF files. The Revit file can be exported in to DWF files and then can be opened by Autodesk Design Review (Figure 18). Design Review enables the users' entire project or product team to view, print, measure, and markup DWF, DWG, DXF, PDF and raster files containing 2D and 3D content. Fully integrated with AutoCAD, Inventor, and Revit, Design Review helps the users easily share drawings, models, maps, and design data with team members, clients, consultants, contractors, partners, suppliers, and other reviewers who may not own or know how to use design software (Autodesk 2009).

Figure 18: The "List View" of Design Review, consists of floor plans, 3D view, ceiling plans, etc.

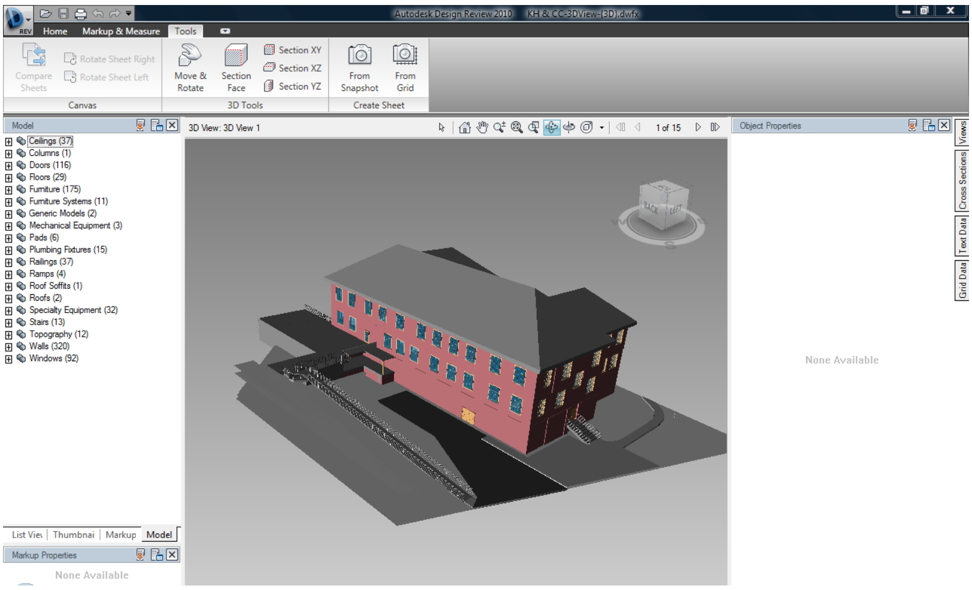


Due to the small size and high interoperability of Design Review files, the users can easily exchange them by email, websites, intranets, and physical media, such as

DVDs. A previous thesis finished by a WPI graduate student Ronald O. Méndez had shown that DWF files and Design Review can be published on a website easily and viewed by common users without major training by the user.

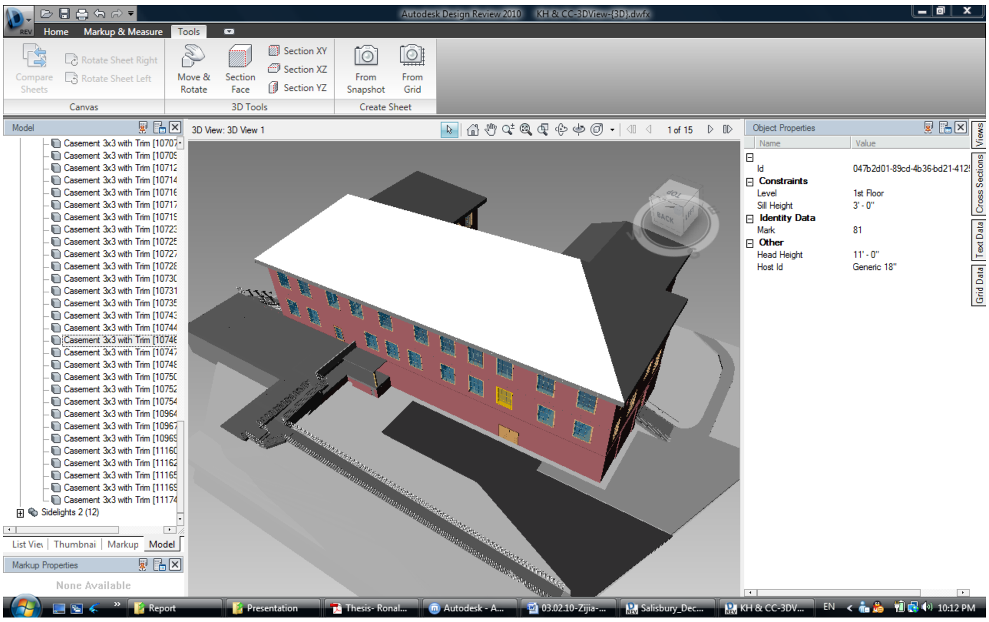
Design Review can be an ideal application for the facility management department. The interface of the program is simple and thus people can adapt it in a short term. The presentations and interviews conducted by the author with staff at facility management department have convinced him that the program is easy to use and value added to their daily work. So overall, the costs for implementation the systems would be minimal.

Figure 19: The "Model" view; consists of project properties, quantity takeoffs, etc.



When exporting from Revit, the users can choose which floor plans or 3D views to be exported. The normal way is to export a 3D view of the whole building, floor plans, and ceiling plans, if necessary, the users can also export egress way plan, floor usage plan (by department, by occupancy, or by hours of use, etc.). Also, the DWF can be made to fit specific needs, for example, the DWF file can only contain the life safety equipment in a building to fulfill the needs of the occupancy safety management. The default 3D view of the whole building is very important because it contained all the information of the building, when clicking on it at the "List View" panel, the 3D view would pop up and all the elements in the building would be listed in the "Model" panel categorized by families(Figure 20). The user can also go to a certain element to view the information on it, for example, the user can select a window (Figure 21) by clicking on either the list or the model, and view the information on the right panel; the selected items are colored with yellow. The users can select or view items in different ways, hide, unhide, or transparent.

Figure 20: The view of properties of a window at Kaven Hall



The users can also have cross section views of the building (Figure 22), which represents a typical section view of floor plan, in order to achieve the effects as shown in Figure 22, the users need to go to one of the amazing thing the user can do is to select a room and view the room information on the right. Also, the users could view the building in vertical or angular section (Figure 23), which would help them easily understand the projects and grab information they want.

Figure 21 Cross Section view of the first floor of Kaven Hall

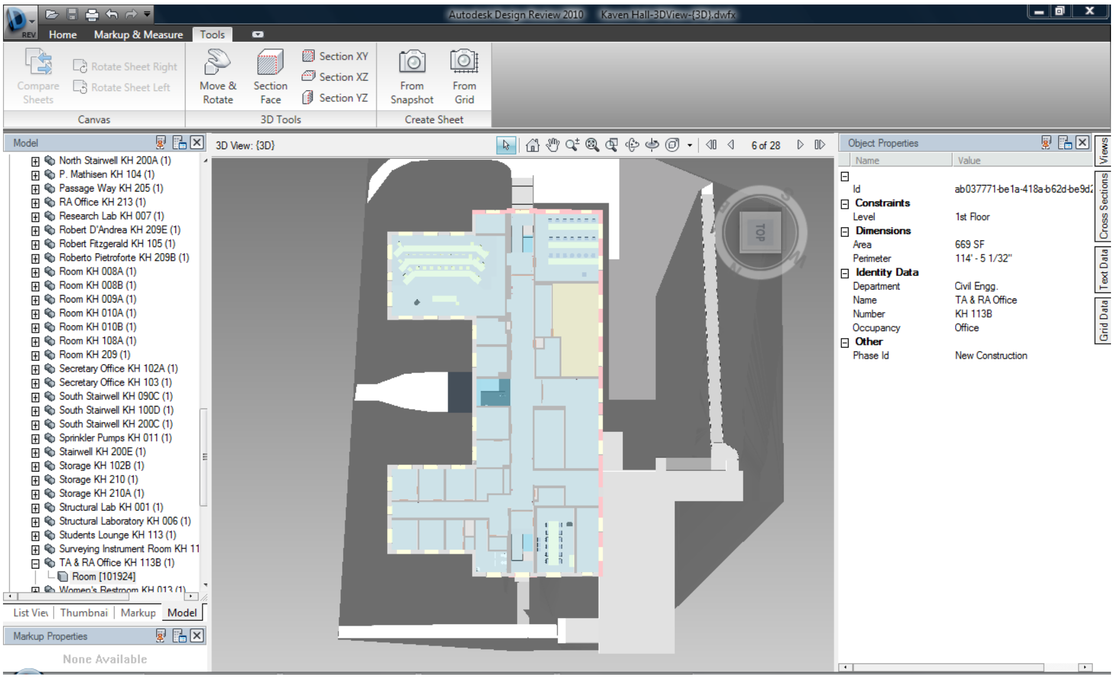


Figure 22 Lobby cross section of Kaven Hall

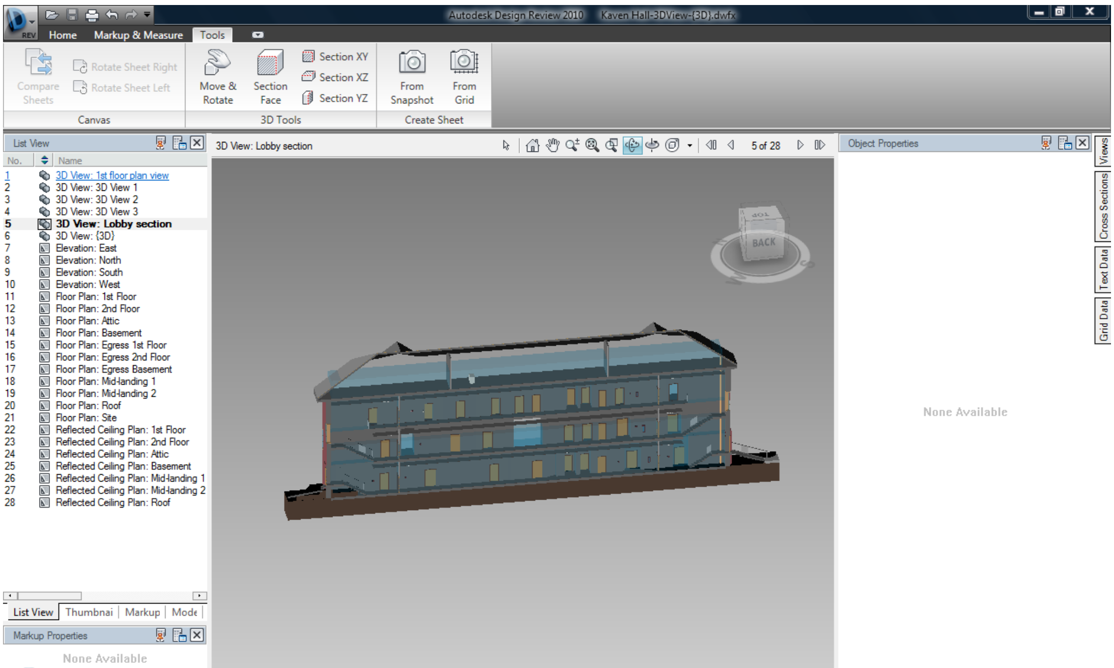
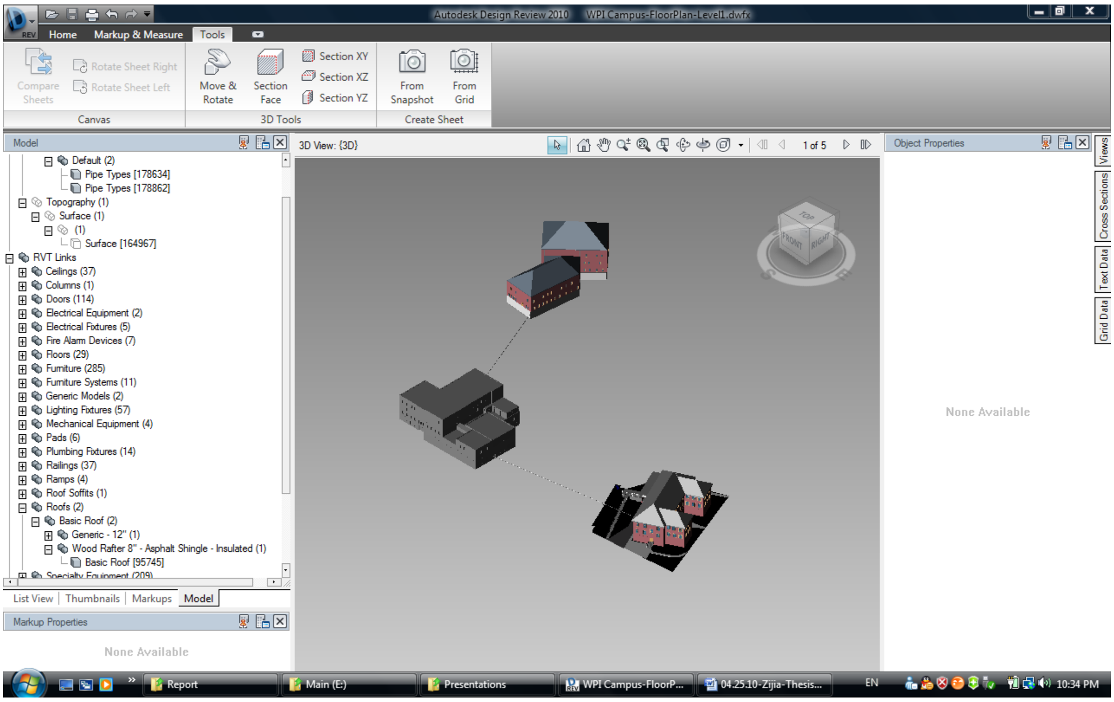


Figure 23: The DWF file of the inter-building systems.



The Design Review can also view multiple buildings together. Figure 23 is the DWF file of inter-building system, the topography was hidden for the illustration purpose. The users can perform the same functions as in the individual building systems, for example, to view the properties of an object (Figure 24), or to view a section of a building (Figure 25). Most importantly, users can select a pipe in the system (Figure 26), which means the BIM based information system is feasible for generating and managing the data of the underground water, steam, fire, sewer systems through its life cycle.

In summary, the BIM based information system adds value for the existing facility management at college campuses, because BIM is capable to include the facilities and equipments in the building or on campus site to fulfill the information needs of Department of Facilities, and the Design Review program can allow the end users to access and extract information more conveniently. However, the most critical issues are what to be modeled and how much level of detail should be modeled. Before

Figure 24: Users can select an object in multiple buildings (the yellow roof)

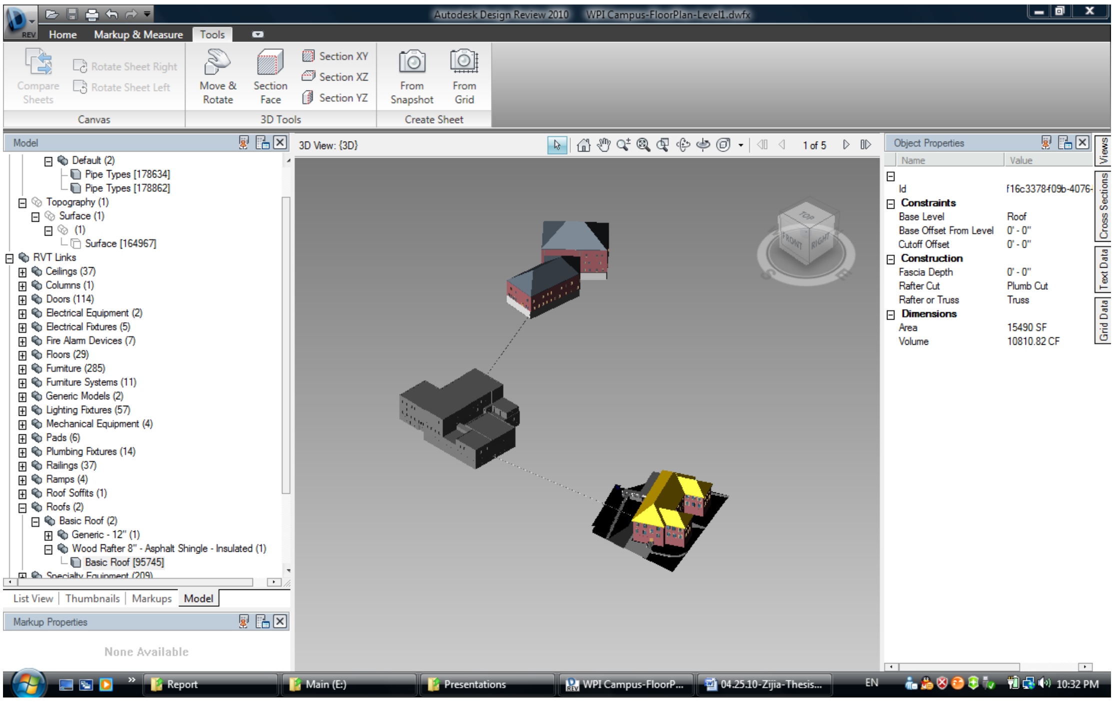


Figure 25: Section views for multiple buildings

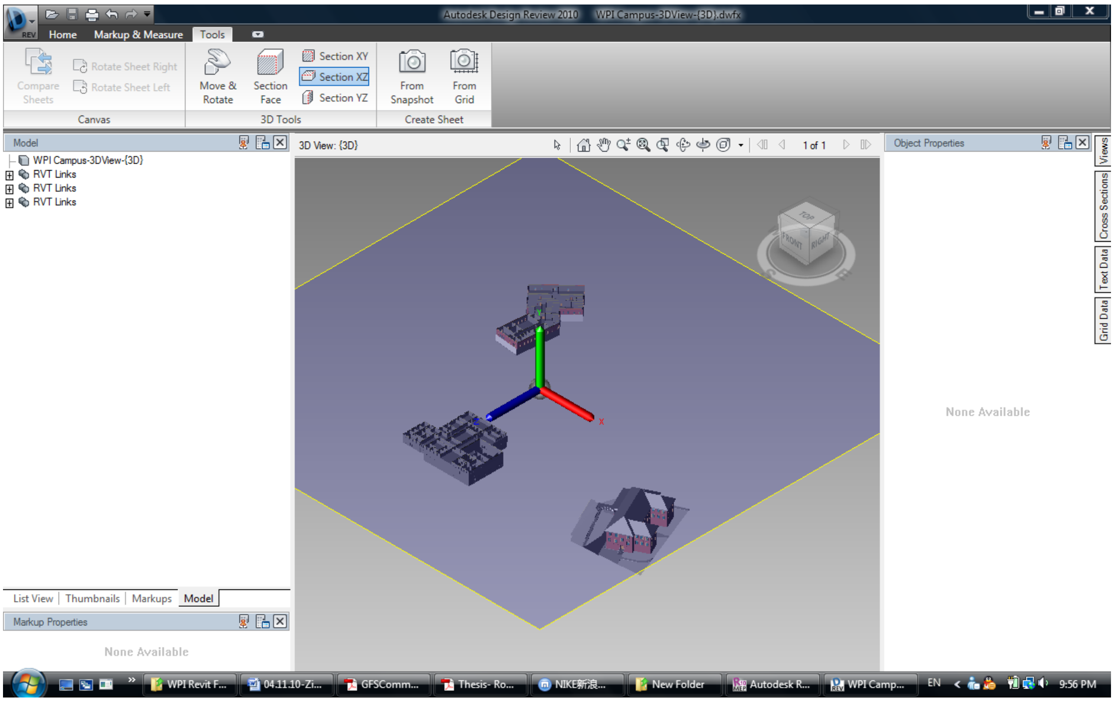
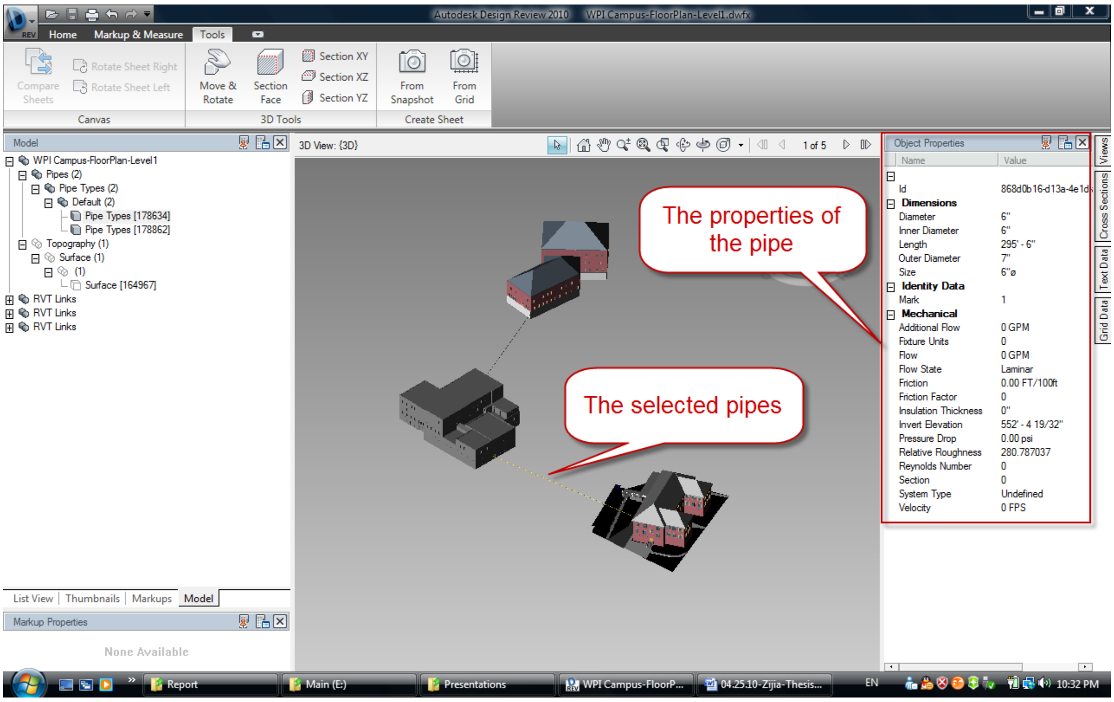


Figure 26: Users can view the properties of a pipe



WPI implementing BIM, a Charrette needs to be set up. The Charrette is an event in which to resolve a problem or an issue in a meeting. The less critical issues, such as who and how to maintain the BIM system, should be addressed based on WPI' situation.

5. Conceptual BIM Execution Plan for WPI

The purpose of BIM Execution Plan is to effectively integrate BIM into the WPI's new project delivery process and existing facility management. The BIM Execution Plan should standardize the overall requirements and details for the future project team and facility management to follow. The plan should also define the scope of BIM, the delivery procedure, the contractual relationship, and the information exchange method. The proposed plan in this research is a conceptual version, because the development and implementation of BIM is a long-term activity and needs participation of a variety of stakeholders. WPI is a beginner on BIM and did not have any experience on BIM project; so it is unnecessary to document a detailed plan for WPI right now. The proposed conceptual plan would only provide a basic BIM guideline for WPI's further use.

The conceptual BIM execution plan for WPI consists of two sections, the first section is for new buildings, which is mainly based on other universities' experience (e.g. Indiana University and Pennsylvania State University) and the BIM status of WPI; the second section is for existing buildings and facilities, which is based on the case study, interviews with WPI staff, and BIM committee meetings.

5.1 Conceptual BIM plan for new buildings and renovations

5.1.1. Overall goals and uses of BIM

Pennsylvania State University had identified 25 BIM uses throughout project life cycle (Figure 7). However, the BIM uses are at the standpoint of the whole project, the owner may not have directly benefited from the implementation of BIM. WPI should help the project participant to identify their specific BIM uses, and also should focus on the following uses, from where WPI can directly benefit: existing conditions modeling, cost estimating, maintenance & scheduling, asset management, space management, and disaster management.

5.1.2. BIM process design

Pennsylvania State University (PSU) uses Business Process Modeling Notation (BPMN) approach to format BIM processes of a specific project. The BPMN approach consists of two levels: level 1, BIM Overview Map; level 2, Detailed BIM Use Process Maps. The Overview Map shows the relationship of BIM Uses which will be employed on the project. The Detailed BIM Use Process Maps are created for each identified BIM Use on the project to clearly define the sequence of various processes to be performed. (Pennsylvania State University 2009)

Each project is unique, so the BIM process should be developed by the project team. These processes provide a detailed plan for implementation of each BIM use.

WPI's knowledge and experience on BIM is very limited, the Department of Facility still was not sure if implementing BIM or not. A new WPI recreation center was prepared to construct at the time of this writing, but the BIM model was created by the design team and shared with the construction manager for their internal use only to prepare a site logistics plan. The lonely BIM behavior does not fit the philosophy of BIM, but still these are benefits derived from this approach when the parties are willing to share models with no contractual implications.

5.1.3. BIM Scope

WPI should build up a Charrette to discuss the future BIM scope. Charrette is an event in which a group of stakeholders gather to develop a focused and sustained effort prior to the deadline of a project. For WPI, the Charrette should include the decision makers, facility managers, professors, space planners, design team, constriction team, and consulting team. The Charrette should discuss the level of details of BIM, the disciplines of BIM. The members of the Charrette should include facility management department, provost department, space planning and professors. Through meetings of BIM committee at WPI, the facility management had defined mechanicals, fire safety, and card access as the primary uses of BIM. So the three disciplines should be submitted to WPI with accurate and detailed information for the further uses.

5.1.4. Organizational Roles and Responsibilities

Indiana University has incorporated Collaborative Process Mapping (CPM) (see Appendix D) in their BIM Execution Plan template. The CPM clearly defined the

BIM roles and responsibilities of each project participant for each phase.

Pennsylvania State University utilizes BIM uses to identify which organization will staff and perform that use.

WPI should refer to both universities' experience and develop the roles and responsibilities of project parties for both individual project and the overall WPI facility management.

5.1.5. Delivery Strategy / Contract

IU implements IPD (Integrated Project Delivery) mandatorily for all the projects. IPD Process Proposal is the contractual documents to be signed by owner, designers, and contractors. The purpose of the IPD Process Proposal is to achieve higher level of integration of project design and construction than the traditional delivery process.

PSU did not mandatorily use any delivery strategy, but suggested on how to select a BIM based strategy and how to write a contractual document.

WPI is familiar with traditional delivery methods but in recent years, the construction management at risk (CM at risk) has been consistently used. The development of Campus Center and Bartlett Center used design-bid-build method, whereas, the on-going Recreation Center project, and the recently completed East Hall used CM at risk. WPI has minimum experience on Design Build but has no experience with IPD strategy. When using a less integrated delivery structure, it is important to work through an initial BIM Execution Process and then assign roles and responsibilities in the contract structure (Pennsylvania State University 2009).WPI should document the roles and responsibilities carefully since BIM can not only change the traditional process but also can increases the degree of communication. Lonely BIM is accepted and encouraged at the beginning of the adoption of BIM to gain knowledge and experience, as well as reducing risks, but social BIM may be strongly encouraged in experienced team participants. Collaboration is of particular importance for that BIM affects the degree of change in the project delivery process.

5.1.6. Communication Procedures

PSU recommends developing electronic and meeting communication procedures, including model management and standard meeting actions and agendas.

WPI should utilize the current electronic communication resources (e.g. MyWPI, eMail system) to manage documents in BIM projects. Due to the large files of BIM, some communication tools may need to be upgraded. WPI should build BIM server for facility management department, and the server can be located at Computing & Communication Center (CCC), where the Maximo server is located. The server should support a set of system that can upload, download, edit, and collaborate within project stakeholders. Also, the document management (file folder structure, permissions and access, folder maintenance, folder notifications, and file naming convention) should also be resolved and defined.

WPI should help set up a Charrette for regular BIM project meeting. The Charrette meeting should be scheduled based on the following procedures, which is recommended by PSU.

- Identify all stakeholders to participate in a meeting which will be using model
- Develop a schedule for any meeting which reference to model content
- Define procedures and protocols for the submission and approval of the model as appropriate.

5.1.7. Technology Infrastructure Needs

The BIM authoring software models should be .rvt format (Autodesk Revit). Because Revit is one of the most popular BIM tools in United States; WPI owned license of Revit in the laboratories of civil engineering, the professors, staff, and students are familiar with Revit. Moreover, the industry leader contractors, such as Gilbane, are using Revit. Indiana University uses Revit for BIM authoring software.

The civil engineering software can be Autodesk Civil 3D, because they are both designed by Autodesk and are highly interoperable. The case study had tested the interoperability.

The coordination and collaboration tools can be .NWD format (Navisworks). With Autodesk Navisworks, project teams can collaborate, coordinate, and communicate more effectively to reduce problems during design and construction. Indiana University uses Navisworks for collaboration and coordination; uses ProjectDox for document management and file sharing.

5.1.8. Model quality

Defining model quality is hard because a BIM model typically contains thousands of items and parameters. Quality control methods should be defined and implemented.

PSU recommended defining BIM model quality based on the following criteria, which were also applicable to WPI:

- Reference model files to a common origin so that they are easy to integrate; for example, the Revit coordination system is controlled by Base Point and Survey Point. The project base point defines the origin (0,0,0) of the project coordinate system. The survey point represents a known point in the physical world, such as a geodetic survey marker. To ensure the integration of model for all parties and disciplines, project team must define the base point and survey point.
- Define a file naming structure for all designers, trades, and subcontractors. Just like paper files, electronic files need to be well-organized and labeled correctly so that they are identifiable and accessible by team members. (Department of Cultural Resources 2008)
- Define an agreement on model accuracy and tolerances. The model of a project participant may have influenced on other team members work. So the tolerances of the model must be defined beforehand so that the responsibilities of each project participant are clear.

Meanwhile, PSU suggested using four methods to check the model accuracy: Visual Check, Interference Check, Standards Check, and Element Validation (Pennsylvania State

University 2009). National Building Information Modeling Standard (published by National Institute of Building Sciences) is good reference for model checking and quality control.

5.2 Conceptual BIM plan for existing buildings and facilities

Existing buildings and facilities contain relatively static data. The data is to support the facility operations, occupancy management, and project management on college campuses. Traditional data storage method is 2D system, which is paper documents, CAD drawings, or PDF files. The storage method system is fragmented and inefficient when it comes to retrieving and updating the parameters for a piece of facility or equipment. For example, when upgrading the current smoke detector with newer styles, the entire ceiling plans ought to be changed. It may take time and effort to maintain the 2d data with the existing inventory. However, BIM is an effective carrier to host, exchange, and upgrade the information. Revit, web page, and other related programs will be used for the media.

The conceptual BIM plan for existing facilities will propose methodologies on what to be included in the plan and how the plan works. The knowledge and experience of the plan is based on the case study, Ronald Mendez's master's thesis, an IQP project by Sibora and Andrew, and the experience from BIM committee. The plan will consist of three parts: 1. the modeling guideline; 2. the interface for end users; 3. information maintenance and upgrade.

5.2.1. The modeling guideline

The case study in Chapter Four had illustrated the feasibility of BIM based information system for college campuses. The case study utilized Kaven Hall as a sample of individual building, and used Goddard Hall, Salisbury Labs as supplementary samples for inter-building systems. The Kaven Hall model has been tested as a qualified solution. Goddard Hall model and Salisbury model were finished to fulfill other academic requirements and therefore may not be qualified models for BIM based information system, but these models can be updated based on what the author did with Kaven Hall.

WPI needs guidelines to standardize the modeling process. WPI owns 39 buildings on and off campus, and for 28 of them there are files of 2D drawings. Typically, the shell of the building model is built up by the original 2D drawings. But the locations and parameters of equipments and devices (e. g. sprinkler heads) need both the 2D drawings and physical inventory check.

The Department of Facilities has concluded a building modeling priority list, which lists the buildings that are necessary to be modeled in a short term. The buildings on the list have complex structure and facilities and need to be managed in BIM. The houses off campus are relatively small and the information can easily retrieved from walk through and experience, so BIM may not be necessary to those houses.

The next issue is to determine who are going to do the modeling job. Students are good resources; they are low cost, creative and faster learners. They can build up the models through academic projects. However, students cannot guarantee the quality and accuracy of the models. They are probably beginners on BIM and may require a lot of training. Architects or third party consultants are the best choice when it comes to finishing the modeling with desired quality and schedule. They are more familiar with BIM tools and can deliver the work effectively. So WPI needs to go through the selection process and sign contract with architects or consultants.

The final issue is what to model. The case study in Chapter Four had already given the answers. It would include the architectural part of the building, the fire safety equipment, life safety equipment and egress system inside the building, and the water, steam, sewer, and fire systems between the buildings.

5.2.2. The interface for end users

A proposed website (http://users.wpi.edu/~zijia_liu/index.html) was designed for the facility management department. The website would serve to deliver the information to the end users and share knowledge and experience with externals. Figure 27 is the structure of the website. The website has four major sections: introduction; building list; downloads; and related links. The Introduction section (Figure 28) should document several paragraphs that explain the recent development of BIM at WPI, in order to gain interest from future BIM project participants, scholars, industry leaders, and other universities. The Building List section will serve as a central database for buildings and facilities (Figure 30). The webpage lists all the buildings on campus, including residential halls. When users click on a hyperlink (Kaven Hall in this case), detailed features of each building will be displayed (Figure 29). The 3D model, floor plans, and ceiling plans are DWF files and are opened by Design Review program, the interface and functions of the program remain the same in a webpage as in the original Revit model (Figure 19). For example, the users can select the roof in Kaven Hall model and view the information (Figure 31). Under the link of Space Utilization are figures that exported directly from Revit model. The inspection and commissioning can be scanned documents; the research by Ronald Mendez had proved the feasibility that includes commissioning documents in a website, along with Revit models. Also, the schedules of the model can be uploaded to the website (Appendix F). The Downloads section can be a database that serves for downloading all the future BIM plans for WPI, just as the webpage of Indiana University BIM Standards (Figure 4).

Figure 27: The hierarchical structure of proposed website

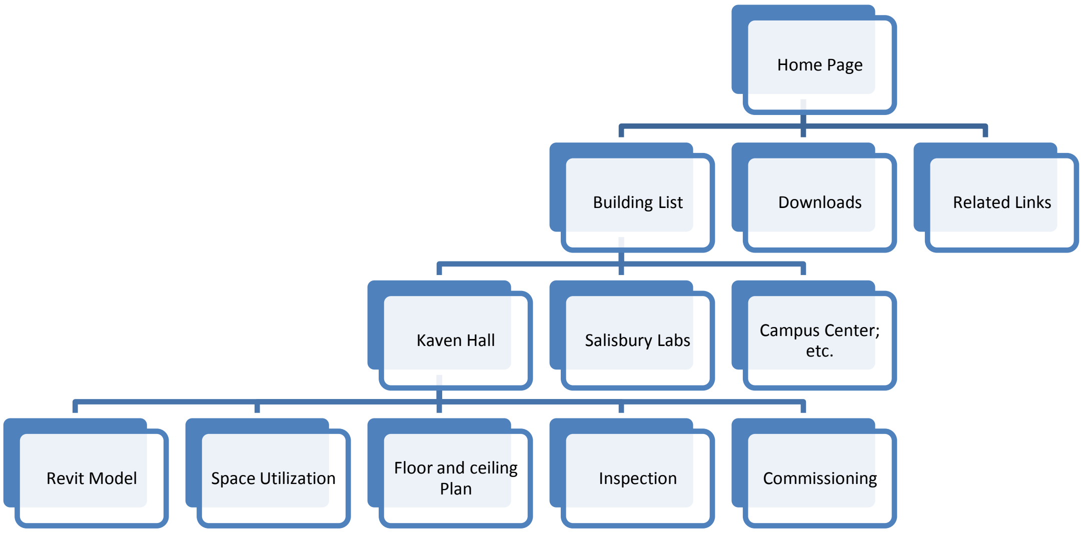


Figure 28: The Home Page of proposed website for WPI BIM Center

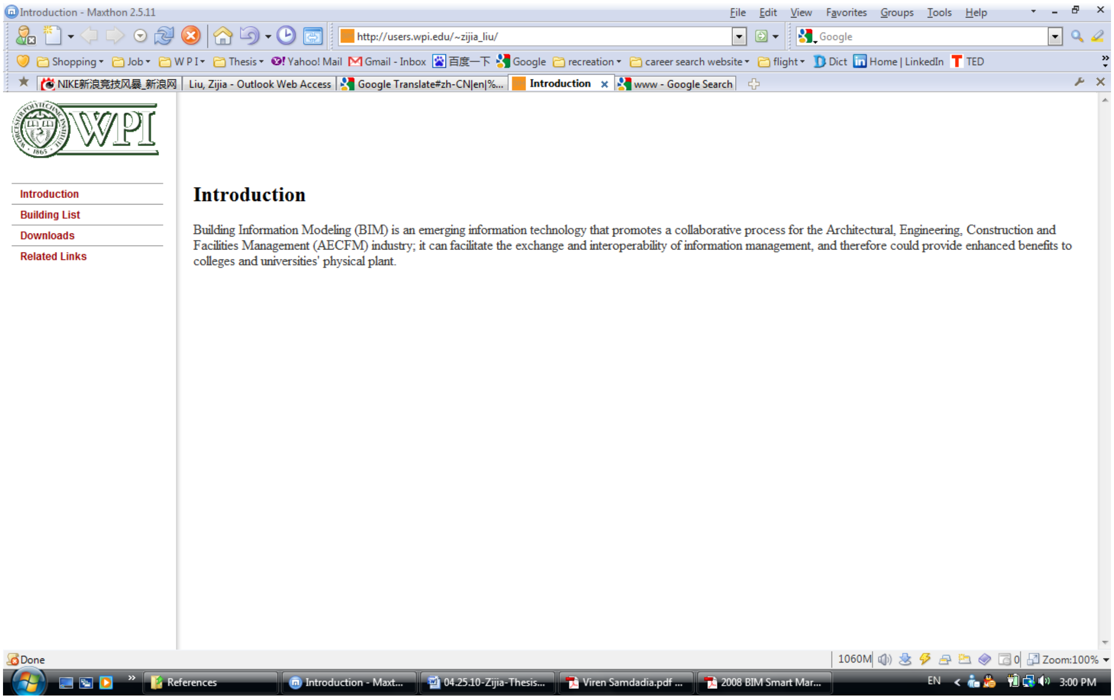
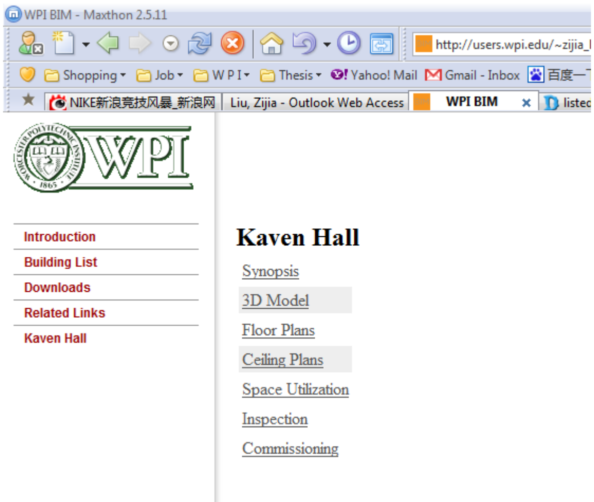


Figure 29: Features in each building



5.2.3. Information maintenance and upgrade

BIM models need to be maintained and upgraded regularly to fulfill the information requirements of facility management department. Currently, WPI is using Maximo work order for the process of maintenance and operation. But this process was only kept in files. The Maximo work order should be coordinated with BIM for better visualization and control. This methodology for proposed information maintenance is based on the original Maximo work order and manual update.

Figure 30: Building List section of proposed website

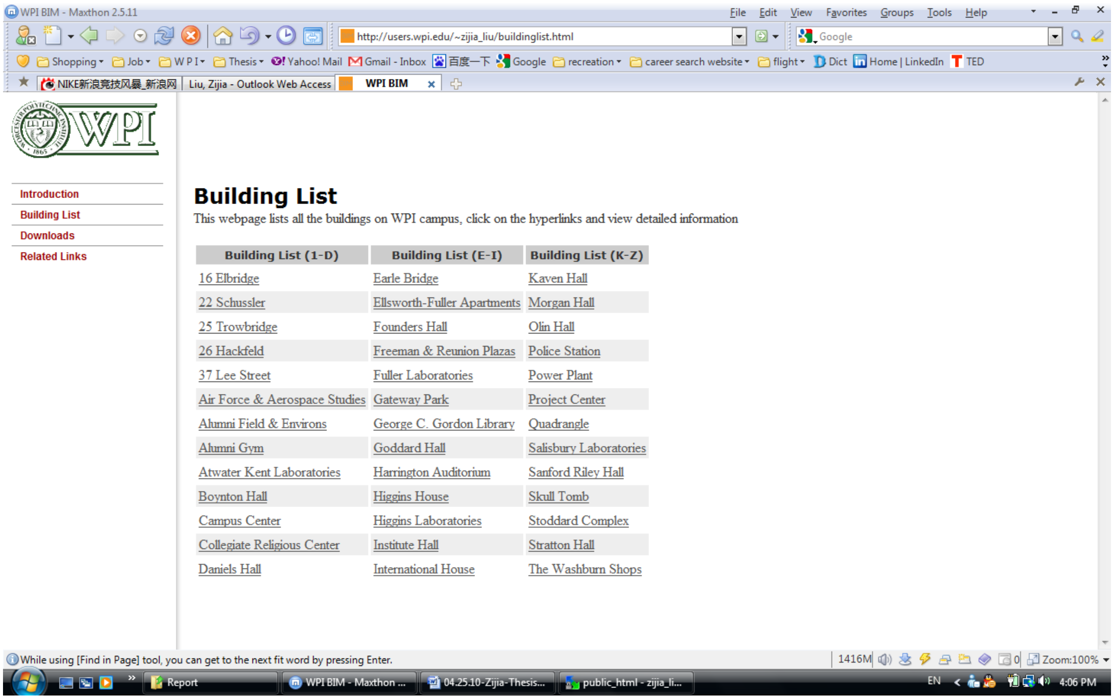


Figure 31: The Kaven Hall model in a webpage

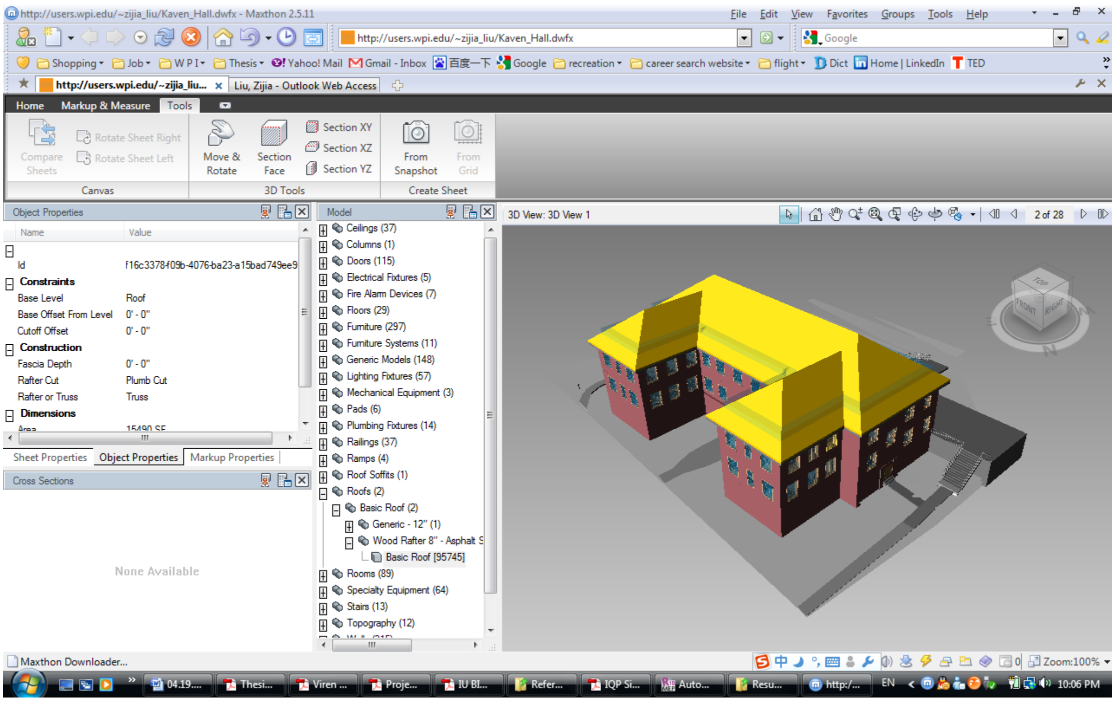


Figure 32: The proposed method for updating BIM model

6. Conclusions & Recommendations

BIM has quickly gained momentum as the technology brings greater collaboration and communication between project participants. Half of the AEC/FM industry is using BIM or BIM-related tools today (McGraw Hill Construction 2009); and the number of BIM users will increase exponentially in the next few years. Designers, contractors, and owners have seen the benefits that are directly or indirectly brought up by BIM. The time spent on design and construction can be shortened due to the 3D visualization and coordination, the owner can enjoy the benefits taken by the reduced schedule. Needless to say, the quality of the project can be improved, the fabrication and construction waste are reduced by the new technology. The owner can receive more valuable as-built information when the project was completed. And therefore the facility management can use more accurate, interoperable, and accessible information system for operation and maintenance.

However, two major hurdles had blocked the implementation of BIM. The first hurdle is that the legal responsibilities among project participants in which BIM practice has not been mature enough. Users prefer to use BIM internally for the first several BIM projects or they develop a lonely BIM before they have the capabilities to handle an integrated environment. The second problem lies with the training costs related to use these programs. BIM tools are complex and require professional teaching to master the practical jobs.

Besides the limitations, the facility managers are starting to focus on BIM for the future information management style. Owners such as Sandia Labs are exploring ways in which BIM can enhance the efficiency of operation and maintenance of the existing buildings. Colleges such as IU and PSU have documented BIM guidelines for new projects to clearly identify the roles and responsibilities of BIM project participants.

The conceptual BIM plan for WPI is just a schematic guideline that originates the BIM implementation work. In order to fully implement BIM for WPI's new construction and operation and maintenance, valuable experience is needed. WPI needs to develop detailed BIM plan gradually along with gaining experience from industry, peer colleges, and real practical experience. One suggestion is that WPI can start from small projects like underground piping renovation; the project can utilize the concept and methodology of the inter-building system in the case study of this thesis. Another issue is that WPI needs to set up a modeling team to manage and update BIM models in regular base. The team can consist of professors, professional BIM expert, staff and students at WPI. The BIM team can also in charge of teaching and training BIM knowledge and philosophy for the facility management department. Moreover, the regular WPI BIM group meeting should be held more frequently to discuss thorough issues that WPI has encountered.

For the future work, the most important is to resolve the interoperability issue between Maximo and Revit. Maximo is better in generating work order process while Revit is good at restoring and communicating information. The two sets of information management style cannot be achieved automatically in a single work flow. Currently, the proposed method is just manually updating Revit model after collecting work order files from Maximo. Another issue is that the inter-building system needed to be developed in more accurate way. The case study just illustrates sample pipes between buildings; the future work should focus on how to build up pipes from 2D drawings with correct parameters. The most intriguing point is that continue developing the website, which serves as a central BIM database for facility management. The website had already been built up with structured solution; the next step is just post the models, plans, files and documents under the exact hyperlink.

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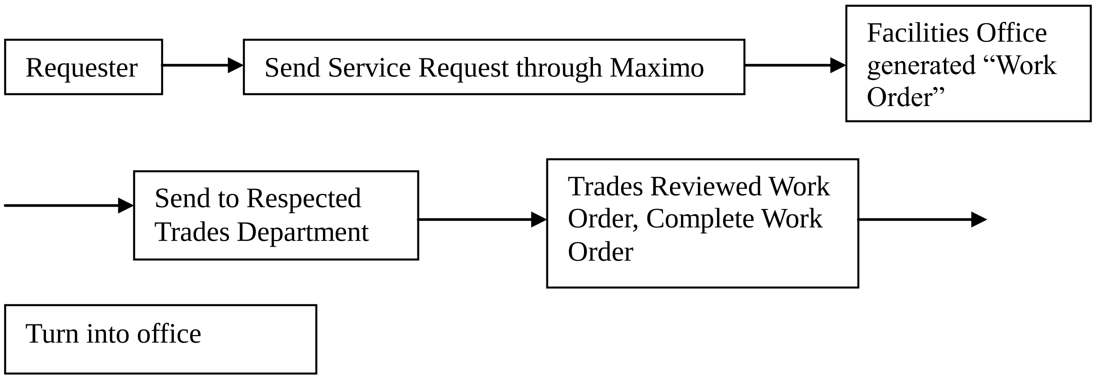
Appendix A - Interviews

Interview with Liz:

Maximo work order (by thesis author)



How do you use Maximo?

For example, someone in Kaven Hall need to create a work order, they would go to our service center (see figure below), they would have to enter their user name and password to get into the interface. Let’s say there is a light out in hallway for example, you have to type in the problem description in the box, then the next step is to select the exact location, this is where BIM is going to be very useful. By clicking on *workflow,* I am going to create a work order. Then I am going to that work order, this is what we would get in my department and my customer service stuff. They would get the customer service request and converted into a work order like I just did. And in doing so they would check to make sure that the description and location, and they would put in particular codes. Then I am going to send the work order to the work shop. The staff at the work shop would send a worker to the location to fix the problem; the worker would make notes on the reports (date, hours, materials, etc). Then they will turn this in to their supervisor, the supervisor will review it and my staff in the department would get a copy of it and record the actual information in the computer.

Locations & Staff

A full list of Department of Facilities is available within the university's organizational chart.
To reach our Customer Service Center, please call +1-508-831-5500.

Connect to Maximo, our work order system

Where is the server of the Maximo?

It is in Fuller Labs.

How do you record costs?

After the report was filled in, we would go to Maximo, load the person in, and enter the number of hours and date, the system would automatically calculate the labor costs based on rates. But at this time, we do not have any materials recorded in, we only take it from the warehouse.

Are the codes defined by your department? Is there possibility that you entered wrong codes?

Yes, it is personally defined by the department, training can help us get the correct information, sometimes people could enter a wrong code, but people in our department can easily understand it.

Who are working on the work order in your department?

There is one person in my department was working on work order every day, she is an expert on that. And if there is more work than usual, another person would assist work order. Also, there is a student, here, who is working at least 15 hours on work order.

Is there any other reports?

Of course, Maximo can sort the information, for example, all the electrical work that was done in Gateway. Similarly, we can find all the emergency work orders in Gateway Park, or work orders in certain period.

What do you think that BIM can help on Maximo?

First, as I said, is the specific location, BIM can help us identify the problem easily and fast.

The second would be asset management, like generators, boilers, and other big equipments which needed to be maintained regularly. BIM can provide the detailed information on it.

Interview with David Messier:

WPI Department of Facilities, 37 Lee Street; Worcester MA

March 2, 2010

What the model does not have but you need?

Chemical fume hood, for example, in Kaven, we have four, room 010 has two, room 007 has one, and room 002 has one. Those are important from the safety prospective, which is when people are using chemicals; the chemical fume hood protects them. And any other chemical buildings have chemical fume hoods.

Bio-safety cabinets (BSC), those are mostly in biology or biochemical labs, on main campus you would fine ten in Goddard. At Gateway campus we have thirty. The BSC are to protect people from injury by bio-chemicals and chemicals.

Emergency showers, wash units, smoke detector and sprinkler head, those which would be other good features if you want to include, because we can actually see them in the model and they also need annual maintenance and inspection.

What information in the Revit model would you be very interested?

Fire Extinguishers, Fire Alarms, Egress Pass, Exit Signs.

We can develop egress pass way from the building model. For instance, you can post exit way of the Kaven Hall Computer Lab from the BIM model; that is one possible use that I would see.

You can highlight fire extinguishers and fire alarms in case of emergency, people can leave and know where the stuff is, and the people from the outside of the building can easily indentify the stuff.

What kind of information do you have? How do you get it?

There is a plan room here; we have all the shop drawings and blueprints. If I need some information, I go to the room and check, for instance, the Kaven Hall; I would pull out the drawings as I can.

How do you keep the information?

It is kept on file, sometimes the documentation is requested by the city.

Appendix B - IU BIM Proficiency Matrix

IU BIM Proficiency Matrix

Category / Number	A - Physical Accuracy of Model	B- IPD Methodology	C - Calculation Ment	D - Location Awarene	E - Content Creation	F - Construction Dat	G - As-Built Modelin	H- FM Data Richness
1	Basic Model Geometry A.1	Creation of A BIM Execution Plan B.1	Basic Model Information Export C.1	Site Orientation D.1	Geometrically Correct Content E.1	Quantity Takeoffs F.1	Post Bid Model Documentation G.1	Space Management Data H.1
	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0
2	Design Requirements A.2	Introduction of Structural and MEP Model B.2	IPD Integration C.2	Existing Environment Awareness D.2	Manufacturer's Specific E.2	Object Scheduling F.2	Coordination Modeling G.2	Asset Management H.2
	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0
3	Design Side Collision Detection A.3	Model Managers Role Defined B.3	Interdisciplinary Calculations C.3	Global Accuracy D.3	Design Intent E.3	Material Procurement F.3	Recapturing Design Intent G.3	Manufacturer Specific Information H.3
	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0
4	Model Accuracy Innovation A.4	IPD Methodology Innovation B.4	Calculations Innovation C.4	Location Innovation D.4	Content Innovation E.4	Construction Innovation F.4	As-Built Innovation G.4	FM Data Innovation H.4
	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0	Point Achieved 0

BIM Maturity

Category	Points Achieved	BIM Maturity Score	BIM Standard		
A - Physical Accuracy of Model	0	0	BIM Score Between 0-12	=	Working Towards BIM
B- IPD Methodology	0		BIM Score Between 13-18	=	Certified BIM
C - Calculation Mentality	0		BIM Score Between 19-24	=	Silver
D - Location Awareness	0		BIM Score Between 25-28	=	Gold
E - Content Creation	0		BIM Score Between 29-32	=	Ideal
F - Construction Data	0				
G - As-Built Modeling	0				
H- FM Data Richness	0				

Appendix C- BIM Proficiency Matrix Submittal Firms (By 3/19/2010)

Indiana University

BIM Proficiency Matrix Submittal Firms

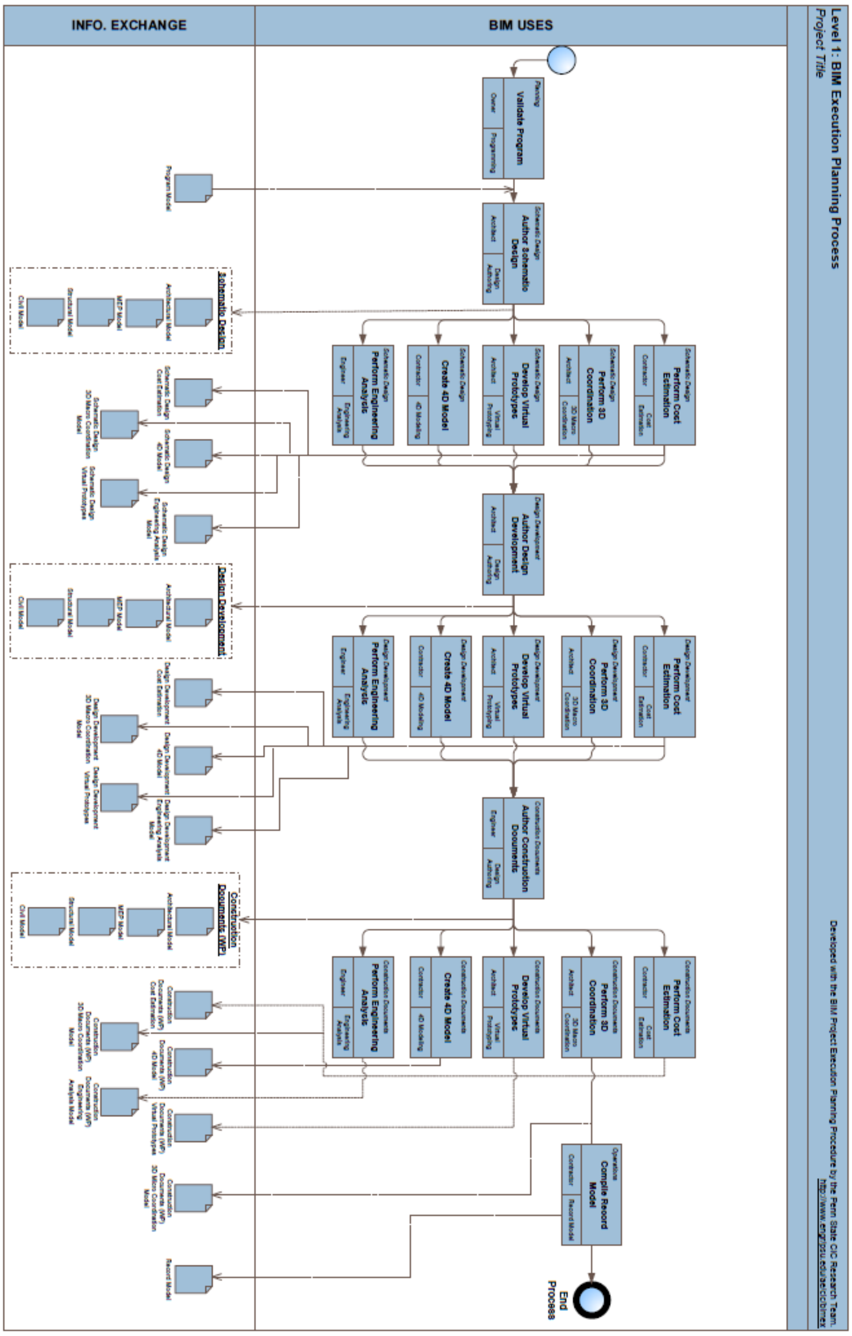
Firm	Contact	Notes
AAA Electric	Michael Wanninger	info not submitted in our IU Proficiency matrix
arcDesign	Andy Hine	
Architecture Design Group (ADG)	Jack Plennert	submitted for IUSB project - BIM team is ADS / Biagi Chance Cummins London Titzer / Ottolino Winters Hubner
Browning Day Mullins Dierdorf Architects	Dan McCloskey	
BSA LifeStructures	Jim Hill	
Cripe Architects + Engineers	Michael Garringer	
Durkin & Villalta Partners Engineering	Kevin Hutton	
FA Wilhelm	Andy Lock	submitted for IU CIB project bid
Hagerman Construction	Bruce Molter	submitted for IU CIB project bid - BIM team is Heapy Engineering / Cripe/McComas
Heapy Engineering	John O'Brien	
InterDesign	David Wietbrock	
L'Acquis Consulting Engineers	Kevin Schulte	
Luckett & Farley	Will Nash	
McComas Engineering	Rod McComas	
Messer Construction	Tim Steigerwald/Andy Burg	submitted for IU CIB project bid
Moore Engineers	Mike Elliot	
MSKTD	Kenneth Etter	
Ratio Architects	Bryan Strube	
Schmidt Associates	Greg Hempstead	
Shiel Sexton	Michael Dilts	submitted for IU CIB project bid
S/L/A/ M Collaborative	Amy Jones	
Synthesis	Dean Trauner	
URS	Steven Robinson	
Weddle Brothers	Lee Carmichael	submitted for IU CIB project bid - BIM team is Heapy Engineering / Cripe/McComas

Appendix D- Collaborative Process Mapping

	Owner	Architect	Consulting Engineers	Construction Manager	Commissioning Agent
Conceptualization/ Program of Requirements	Provide requirements related to form, function, cost and schedule	Begin design intent model with massing concepts and site considerations	Provide feedback on initial building performance goals and requirements	Provide feedback on initial building cost, schedule, and constructability	Provide feedback on advanced commissioning requirements
Criteria Design/Schematic Design	Provide design review and to further refine design requirements	Refine Design Model with new input from Owner, Consulting Engineers, and Construction Manager. Conduct Reverse Phase Scheduling Activity	Provide schematic energy modeling and system iterations as Design Model continues to develop	Provide design review and continued feedback on cost, schedule, and constructability	Refine advanced commissioning requirements
Detailed Design/Design Development	Department design reviews. Final approval of project design and metrics	Continue to refine Design Model. Introduce consultants models and perform model coordination	Create Discipline specific Design Models. Create detailed energy model.	Create Construction Model for simulation, coordination, estimates, and schedule	Review design model for all disciplines
Implementation Documents/Construction Documents		Finalize Design Model, Construction Documents, and Specifications	Finalize Discipline specific Design Models and Final Energy Model	Enhance Construction Model and perform final estimate and final construction schedule	Review design model for all disciplines
Agency Coordination/Final Buyout	Assist with code compliance negotiations and permitting	Work with agencies on code compliances, plan acceptance and respond to construction RFI's	Work with agencies on code compliances, plan acceptance and respond to construction RFI's	Manage bid process, project buyout, and preconstruction RFI's	
Construction	Monitor construction and give input to construction changes and issues	Perform contract administration, update Design Model with changes	Assist with RFI's and update Discipline specific Design Models, field conditions, and commissioning	Manage construction with subcontractors and suppliers, inform changes to Design Model	Observe construction and perform advanced commissioning.
Facility	Engage Architect and	Coordinate information			

Management	Facilities Group for model turnover to staff.	exchange through model to Facilities Group			

Appendix E - BIM Execution Planning Process



Appendix F- Sample Room Schedule of Kaven Hall model

	A	B	C	D	E	F	G	H
1	Room Schedule							
2	Number	Name	Area	Level	Occupancy	Department	Student Capacity	Availability
3								
4	KH 010	Environmental Infrastructure Program	1231 SF	Basement	Lab	Civil Engg.		
5	KH 001	Structural Lab	342 SF	Basement	Lab	Civil Engg.		
6	KH 002	Fuller Geotechnical Laboratory	1499 SF	Basement	Lab	Civil Engg.		
7	KH 006	Structural Laboratory	1031 SF	Basement	Lab	Civil Engg.		
8	KH 008	Highway Infrastructure Program	547 SF	Basement	Lab	Civil Engg.		
9	KH 003	Fuller Geotechnical Laboratory / Office	221 SF	Basement	Lab	Civil Engg.		
10	KH 014	Men's Restroom	95 SF	Basement	Mechanical	Plant Services		
11	KH 013	Women's Restroom	64 SF	Basement	Mechanical	Plant Services		
12	KH 090A	North Stairwell	227 SF	Basement	Circulation	Plant Services		
13	KH 012	Building Data Closet	63 SF	Basement	Support	CCC		
14	KH 011	Sprinkler Pumps	110 SF	Basement	Mechanical	Plant Services		
15	KH 010A	Room	117 SF	Basement	Lab	Civil Engg.		
16	KH 010B	Room	172 SF	Basement	Lab	Civil Engg.		
17	KH 015	Room	255 SF	Basement	Mechanical	Plant Services		
18	KH 004	Custodian	143 SF	Basement	Mechanical	Plant Services		
19	KH 005	Electrical Room	274 SF	Basement	Mechanical	Plant Services		
20	KH 008B	Room	131 SF	Basement	Lab	Civil Engg.		
21	KH 008A	Room	74 SF	Basement	Lab	Civil Engg.		
22	KH 009A	Room	82 SF	Basement	Lab	Civil Engg.		
23	KH 009	Machine Shop	533 SF	Basement	Support	Civil Engg.		
24	KH 007	Research Lab	899 SF	Basement	Lab	Civil Engg.		
25	KH 090C	South Stairwell	221 SF	Basement	Circulation	Plant Services		
26	KH 090B	Basement Corridor	687 SF	Basement	Circulation	Plant Services		
27	23		9017 SF					
28	KH 113	Students Lounge	614 SF	1st Floor	General Use	Civil Engg.		Occupied
29	KH 113B	TA & RA Office	669 SF	1st Floor	Office	Civil Engg.		Occupied
30	KH 100B	1st Floor Corridor	946 SF	1st Floor	Circulation	Plant Services		
31	KH 115	Class Room	728 SF	1st Floor	Classroom	Projects & Registrars		Occupied
32	KH 117	Jayachandran	148 SF	1st Floor	Office	Civil Engg.		
33	KH 101	Frederick Hart	170 SF	1st Floor	Office	Civil Engg.		
34	KH 102	Department Office	147 SF	1st Floor	Office	Civil Engg.		
35	KH 104	P. Mathisen	129 SF	1st Floor	Office	Civil Engg.		
36	KH 105	Robert Fitzgerald	132 SF	1st Floor	Office	Civil Engg.		
37	KH 106	DeFalco	130 SF	1st Floor	Office	Civil Engg.		
38	KH 107	Jeannie Plummer	126 SF	1st Floor	Office	Civil Engg.		
39	KH 108	Women's restroom	89 SF	1st Floor	Mechanical	Plant Services		
40	KH 109	Bathroom	173 SF	1st Floor	Mechanical	Plant Services		
41	KH 110	Custodian	38 SF	1st Floor	Mechanical	Plant Services		Available
42	KH 111B	Conference Room	413 SF	1st Floor	Office	Civil Engg.		Available
43	KH 111A	Surveying Instrument Room	248 SF	1st Floor	Lab	Civil Engg.		Available
44	KH 112	Copy/Blueprint Room	271 SF	1st Floor	Office	Civil Engg.		Occupied
45	KH 116	Fuller Lecture Hall	1557 SF	1st Floor	Classroom	Projects & Registrars		Occupied
46	KH 117A	Bergendahl	128 SF	1st Floor	Office	Civil Engg.		
47	KH 102A	Secretary Office	119 SF	1st Floor	Office	Civil Engg.		
48	KH 103	Secretary Office	151 SF	1st Floor	Office	Civil Engg.		
49	KH 100D	South Stairwell	226 SF	1st Floor	Circulation	Plant Services		
50	KH 100C	1st Floor Hallway	159 SF	1st Floor	Circulation	Plant Services		
51	KH 100F	1st Floor Corridor	402 SF	1st Floor	Circulation	Plant Services		
52	KH 100E	1st Floor Corridor	284 SF	1st Floor	Circulation	Plant Services		
53	KH 102B	Storage	17 SF	1st Floor	Mechanical	Plant Services		
54	KH 108A	Room	20 SF	1st Floor	Mechanical	Plant Services		
55	KH 100A	North Stairwell	232 SF	1st Floor	Circulation	Plant Services		
56	KH 116A	Classroom Closet	100 SF	1st Floor	Classroom	Projects & Registrars		
57	KH 119	General Storage	138 SF	1st Floor	Office	Chemical Engg.		
58	KH 114	Computer Room	140 SF	1st Floor	Office	Civil Engg.		
59	KH 120	Custodian	76 SF	1st Floor	Mechanical	Plant Services		Available
60	32		8917 SF					
61	KH 202A	G. F. Salazar	152 SF	2nd Floor	Office	Civil Engg.		
62	KH 202	CAD Lab	1484 SF	2nd Floor	Lab	Civil Engg.		
63	KH 203	Graduate Office	688 SF	2nd Floor	Office	Civil Engg.		
64	KH 207	Computer Lab	1289 SF	2nd Floor	Lab	Mathematical Dept.		
65	KH 200B	2nd Floor Corridor	907 SF	2nd Floor	Circulation	Plant Services		
66	KH 209D	Malcolm Ray	127 SF	2nd Floor	Office	Civil Engg.		
67	KH 209C	M. S. Fitzpatrick	125 SF	2nd Floor	Office	Civil Engg.		
68	KH 209B	Roberto Pietroforte	134 SF	2nd Floor	Office	Civil Engg.		
69	KH 209A	Rajib Mallick	131 SF	2nd Floor	Office	Civil Engg.		
70	KH 209E	Robert D'Andrea	237 SF	2nd Floor	Office	Civil Engg.		
71	KH 208	James O'Shaughnessy	211 SF	2nd Floor	Office	Civil Engg.		
72	KH 210	Storage	72 SF	2nd Floor	Mechanical	Plant Services		
73	KH 210A	Storage	79 SF	2nd Floor	Mechanical	Plant Services		
74	KH 209	Room	75 SF	2nd Floor	Mechanical	Plant Services		
75	KH 213	RA Office	102 SF	2nd Floor	Office	Civil Engg.		
76	KH 214	D. Pelligrino	123 SF	2nd Floor	Office	Civil Engg.		
77	KH 201	Albano	192 SF	2nd Floor	Office	Civil Engg.		
78	KH 204	Class Room	628 SF	2nd Floor	Classroom	Projects & Registrars		
79	KH 206	Tahar El-Korchi	250 SF	2nd Floor	Office	Civil Engg.		
80	KH 200E	Stairwell	92 SF	2nd Floor	Circulation	Plant Services		
81	KH 207B	2nd Floor Vestibule	106 SF	2nd Floor	Lab	Civil Engg.		
82	KH 211	Women's restroom	119 SF	2nd Floor	Mechanical	Plant Services		
83	KH 211	Men's restroom	102 SF	2nd Floor	Mechanical	Plant Services		
84	KH 200C	South Stairwell	226 SF	2nd Floor	Circulation	Plant Services		
85	KH 200A	North Stairwell	232 SF	2nd Floor	Circulation	Plant Services		
86	KH 205	Passage Way	43 SF	2nd Floor	Circulation	Plant Services		
87	KH 212	Custodian	44 SF	2nd Floor	Mechanical	Plant Services		
88	KH 200D	2nd Floor Corridor	365 SF	2nd Floor	Circulation	Plant Services		
89	KH 207A	Computer Lab	344 SF	2nd Floor	Office	Civil Engg.		
90	KH 207C	Computer lab	229 SF	2nd Floor	Office	Civil Engg.		
91	30		8907 SF					
92	KH 303	Attic Storage	3194 SF	Attic	Support	Civil Engg.		
93	KH 301	Attic Storage	3327 SF	Attic	Office	Civil Engg.		
94	KH 302	Attic Storage	2726 SF	Attic	Office	Civil Engg.		
95	KH 300A	Attic Stairwell	92 SF	Attic	Circulation	Plant Services		
96	4		9338 SF					
97	Grand total: 89		36179 SF					
98								
99								
100								
101								
102								
103								

Room Schedule