THE

BUILDING INFORMATION MODEL

IN FACILITIES MANAGEMENT

by

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Abstract

The construction industry's traditional resistance to incorporate change has prevented benefits from technological advancements to accrue. One area in which technology shows potential to benefit the industry is in addressing the existing communication gaps between the designer, builder, and owner. This gap is more evident in the operation and maintenance of a building. At project completion, an owner also receives information of the building. This information is comprised of as-built drawings, operation and maintenance manuals, warranties, and other documents. However, there is additional and valuable information for the owner generated throughout the design and construction process that goes unrecorded or is not passed unto the owner at project completion.

The Building Information Model (BIM) is a digital collection of well coordinated information about the design and construction of a building in the form of an integrated database, where information is generated as the digital model is produced. The intent of the research is to explore how the BIM could be used to provide continuity in the flow of information in a coordinated and comprehensive manner from the design and construction of the building to its occupation and operation by the owner. Through literature review, a case study, and interviews with facilities management personnel of four Worcester area universities, it was found that use of the BIM is perceived of modest value because of their current preference for paper submittals, resistance to learning new software, and accessibility by people of all levels in the organization.

The Internet is considered to be a tool that could greatly contribute to overcome the resistance of using information generated and coordinated through BIM. Therefore, a

prototype website was developed using information about the design and construction of the recently completed WPI Bartlett Center. This information was partially generated by BIM and it also contains digitized information about other aspects of the building. The website contains a BIM-generated 3D model and samples of the operation and maintenance manuals, warranties, and submittals. The implementation of a website was found to be promising because of increased access to information, high usability, and variety of content.

Acknowledgements

"Todo lo puedo en Cristo que me fortalece." Filipenses 4:13

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1.0 Introduction

In a construction project, there are communication gaps between the various project participants such as the designer, builder, and owner. The gap is much more evident in the operation and maintenance of a facility. When a building is completed, the owner does not just obtain a new building, but also a plethora of project information in paper and electronic form. It is then up to the owner to make sense of it all at their own expense of time and money. Technology has the potential to fill in the communication gaps that exist, but it has been prevented by the industry's resistance to incorporate technological innovations. Cellular phones and electronic mail have influenced business, education, and practically everything else in life, as well as the construction industry. Documents and drawings can be sent to someone in an instant, and people can talk to each other halfway around the world with wireless phones. Yet, the construction industry still has not fully benefited from the potential that technology has and lags behind other industries.

The construction industry is a vital part of the economy of the United States, accounting for over 8 percent of the nation's gross domestic product (Bogdan, 2000). It is the largest manufacturing sector in the U.S. and second to the government as the largest employer. However, it is characterized as being very diverse, competitive, and fragmented. The participants must invest a substantial amount of money, time, and effort and incur a large amount of risk in order to gain or obtain a small profit (Mulligan, 2004). The vast majority of the products of construction are singular events pieced together by a temporary organization comprised of a multitude of entities. It is not surprising that the general concept has been to get the job done, make a profit, and move on. Due to the fragmentation of the industry, the design, fabrication, and construction data produced by one group is usually created instead of being reused (Bogdan, 2000). Proposed solutions have included the implementation design-build, lean construction, and construction management, but these measures have focused primarily on time, quality, and cost. However, this has still not completely resolved a problem that seems to be process-related instead of product related.

The construction industry has partially benefited from the advances in digital technology. Documents and drawings can be given to others in seconds instead of days, and people can verbally communicate with each other via cellular phones without having to stay in one place. The Internet has made a vast quantity of information available to everyone. Yet, technological advancements consist of more that phones and email. Technology has changed the process by which tasks are done. For example, drawings used to be created by hand on paper with a pen or pencil. The arrival of the computer and computer aided drafting (CAD) slightly changed the manner in which drawings were completed. Designers got the opportunity and capability to electronically produce and print drawings. However, regardless of whether the drawings were drawn by hand or electronically, content changes still had to be manually integrated into the drawing. At least with CAD, a drawing did not have to be completely recreated if a change was made. The change just had to be implemented into where it was made, unlike a hand drawn print which would require additional items such as white out to take care of unsightly eraser and smudge marks.

Yet, there were still difficulties. CAD seemed to just take the designer and place him/her in front of the computer. Really, all this seemed to do was transform the pencil into a computer mouse. There are concerns about since errors and omissions still occur. CAD has never possessed the ability to fully display the relationship among drawing entities. For instance, floor plans of a building could be designed in the same CAD file, yet the CAD software never had the ability to make the connection that the floors drawn are of the same building. Instead, the user has to interpret and convey that important message to any person who might need it.

The drafting method was perhaps made easier but it did not capture the intent of the designer. A two dimensional plan would show only the end product and nothing about the thought process and rationale. So much time, effort, and thought put into a product (for a building), and all there was to show were pieces of paper with lines on it. Unless, someone knew how to interpret these drawings, they were just paper with markings. Hence, a 2D plan having the inability to give parties, such as owners or end users who receive and use the plans for the life of the building, any relevant information that is also readily accessible. The greater need is to apply technology to the transfer of information in all facets of the life cycle of a building.

The building information model (BIM) is a technological approach to storing and conveying information about a building, with the ability to visually display building components in a three dimensional view. The three dimensional capability is enhanced by the parametric modeling engine, which automatically interrelates building objects to other objects and coordinates changes and revisions across the project deliverables (Rundell and Stowe, 2005). For instance, a change to the length of a wall in a building drawing is automatically reflected in the walls that connect to it. The idea is that the BIM produces a faster, cheaper, more accurate, and better-coordinated project experience during design, construction, and future use.

However, the use of the BIM has been limited and rudimentary. The BIM has been primarily applied to the design and construction phase of a project, and for good reason. Designers and contractors can better understand each other, change orders and time can be reduced and even costs. Yet, widespread use of the BIM is held back by the construction industry's leeriness of technological changes. In addition, the design and construction phase have been designated by designers and builders to be separate from the operations and management phase. So what still remains to be seen is the integration of the entire project experience.

This project intends to explore the application of the BIM in building projects for its occupancy and operations phase. The question is how and to what degree can the BIM make a difference. Instead of the current practice of the storage of papers, books, drawings, and discs usually provided by the constructors, the BIM would allow the designer to transfer the building information to the owner providing the owner with a priceless collection of information about the building generated since the project's conception. As a result, the BIM can enhance the future use of a building and its information, benefit the end user with life cycle analysis, and even change the way maintenance is accomplished by making building information readily available, accessible, and understandable.

2.0 Background

2.1 Industry Fragmentation

The construction industry is a substantial part of the economy of the United States. It is 8% of the national gross domestic product (Bogdan, 2000). Yet, this industry is very fragmented. Unlike some industries such as plane design and construction where few companies can perform the work, the building/infrastructure construction industry is composed of a myriad of firms, companies, and business entities that offer countless services ranging from design to construction to management. The U.S. Department of Labor reported that almost two out of three businesses were employed fewer than five people (U.S. DOL, 2006). In addition, there are a very large number of self employed people. The high number of companies can be attributed to the low barrier entry into the industry, proving the old adage about just needing a hammer and pickup truck to get started. The design branch of the construction industry primarily entails architects, engineers, and other consultants such as acoustical engineers. Construction is the most diverse area of the industry because it branches into building and infrastructure construction. Management refers to construction project management, which are basically general contractors and construction management firms.

A construction project demands a wide range of jobs and services, varying from concrete workers to elevator technicians to roofers. Along with this is the high level of subcontracting that the industry possesses, because given the very diverse job opportunities, there are a myriad of companies and firms that offer construction services. Consequently, the large number of construction-related businesses gives way to a high level of competitiveness. This competitiveness results in relatively low prices. Arguably, these low costs are a bargain because of the high level of risk that the participant incurs for being involved in a construction project. As a result of the industry's nature, there are significant negative impacts such as perceived low productivity, cost and time overruns, conflicts and disputes, and the resulting claims and time-consuming litigation (Australian CD-ISR, 2004). Especially in the United States, litigation seems almost have become a part of the construction industry. The extended consequences of the fragmentation are:

- inadequate capture, structuring, prioritization, and implementation of client needs
- fragmentation of design, fabrication, and construction data with the data being generated by one party not being re-used downstream
- development of pseudo-optimal design solution
- lack of integration, coordination, and collaboration between the various functional disciplines involved in the life-cycle aspects of the project
- poor communication of design intent and rationale, which leads to unwarranted design changes, inadequate design specifications, unnecessary liability claims, and increases in project time and cost.

The construction of a building project sets up a temporary business alliance. Several parties are brought together to contribute towards the completion of a single project. Once the project is completed, the relationship between the participants is over, and the participants move on to another temporary business alliance. During the project, the relationship between the construction project participants is normally complex that involves many parameters that extend across technical, functional, business, and human dimensions (Australian CD-ISR, 2004). Consequently, a lot of effort, time, and money must be invested into the intensive collaboration among project participants in order to synchronize the input and output of the organization. In other words, in order to achieve the end goal, a substantial amount of extraneous work must be done. One area is that of project information.

Project information is processed data produced by many sources, at many levels of abstraction and detail, but retained by the creator of that information, which contributes to the industry fragmentation. Another factor is the exchange of the project information between the designers and the constructors, which mainly occurs on paper. As a result, about two-thirds of construction problems are caused by inadequate communication and exchange of information and data (Australian CD-ISR, 2004).

Another consequence of fragmentation is the adversarial relationship between the designer and the builders. Consequently, information and data are not readily shared. The adversarial relationship also extends to the project owner. The project owner is usually and rightfully worried about the project budget before and during construction, and the contractor typically feels the brunt of the stereotype that describes him/her as a cheating and sleazy project partner. Furthermore, there is a discontinuity between the project team and the life of a building. Typically, builders and designers seem to forget about the end use of the project unless something goes wrong after completion or the owner is dissatisfied with the product.

The desire to overcome the industry fragmentation has resulted in several approaches (Australian CD-ISR, 2004). One is design-build (DB), which highlights the fact that there is a single point of responsibility for the project owner to deal with. Theoretically, because design and construction are integrated into one entity, project duration is reduced as well as claims and liabilities; in turn the work quality is increased.

However, it is not applicable for every type of building project. Another option is design-build-operate (DBO), where the design-build entity is responsible for the operation of the facility for a specified amount of time. The hope is that because the DB firm must operate the facility, the DB party will better incorporate operation issues into the design and construction phases and erect a better building. Apparently, DBO seems like the solution to closing the gap between the construction and operation, but it is limited by the interest that projects owners have, which is cost, and its applicability to projects. Lastly, information technology is another option to address the fragmentation with the use of a Web-based communications system (Mulligan, 2004). On the Web, the system stores drawings, submittals, estimates, and various other information that would be needed by project participants. The system can be used to instantly share, visualize, and communicate project information between any project participant like staff, clients, suppliers, and contractors because it can be readily accessed. It is indeed an improvement in the communication among the project staff, but there are still limitations such as two-dimensional computer-generated CAD drawings.

Another characteristic of the construction industry is the resistance against the adoption of new technologies. Despite the potential to save time and money with the implementation of new technology, the culture has been to steer away from it. Part of the resistance is attributed to having to learn new software and the learning curve that it requires. Also, there is the concept of not straying away from the tried and true. Using new methods do involve some amount of risk. However, if anything has really influenced this matter, it is the consequences and repercussions that follow if a project does not go as planned, such as increased costs and time, even when using the traditional methods, never mind innovative methods and procedures. Usually, these side effects have resulted in conflicts, arbitration, and litigation, the last being the most costly and damaging. As one builder put it, “It’s like trying to teach a child to ride a bike, and then threatening to hit the child with a baseball bat if they fall off even once. The child won’t want to get back on the bike.”

2.1.1 Interoperability

In 2004, the U.S. National Institute for Standards and Technology published a report stating the capital facilities construction industry wastes $15.8 billion annually because of poor interoperability among CAD, engineering, and other software systems. The $15.8 billion figure was also a conservative estimate. Interoperability is defined as the ability to manage and communicate electronic product and project data between collaborating firms’ and within individual companies’ design, construction, maintenance, and business process systems (NIST, 2004). Evidence of poor interoperability is the manual re-entry of data, duplication of business functions, and the reliance paper-based information systems (Newton, 2004). The problems of interoperability stem from the highly fragmented nature of the construction industry further compounded by the large number of small companies that have not adopted advanced information technologies. Additional causes are the industry’s continued paper-based business practices, lack of standardization, and inconsistent technology adaptation among stakeholders.

Of the $15.8 billion that are squandered, about $5.2 billion is sustained among architects, engineers, general contractors, fabricators, and suppliers. Architects and engineers were responsible for $1.2 billion, general contractors for $1.8 billion, and specialty fabricators and suppliers for $2.2 billion. The remaining $10.6 billion, roughly two-thirds of the $15.8, is borne by owners and operators during the operation and maintenance phase of a building. The loss is substantially high because of the long term commitment that owners and operators have. The $10.6 billion loss was attributed to using redundant information technology systems, time consuming information verification and validation, inefficient business process management, and costly information delay to employees waiting for the necessary information to resolve a maintenance issue. It is evident a high price is paid because of the poor interoperability that exists between design, constructors, and owners. Better measures should be considered.

2.2 Computer Aided Design

Computer Aided Design (CAD) was innovative because it replaced the pencil (or pen) with a mouse, computerized the production of paper drawings, and facilitated the drawing procedure. For example, right angles can be drawn easily in CAD and CAD can copy lines as many times as desired without the need to measure them manually. Yet, the introduction of CAD into the construction industry did not change the construction process; instead the same method that has been used for centuries was still used (Bedrick, 2005). For instance, a designer (architect) imagines an idea, a building, in 3D in response to the client's program. The designer draws it from different perspectives or angles to show what it is and then has to deconstruct the 3D idea into a 2D graphical representation, generally in the form of floor plans, sections, and elevations. The 2D models are then given to the construction team, consisting of engineers and constructors.

Structural engineers have to engineer the structural frame, while mechanical engineers design the inner workings of the building. The structural engineers have to give their 2D representations to fabricators, who have to represent all their respective pieces and parts in 2D. In the vast majority of cases, the various engineers do not communicate or collaborate with one another to identify any problems or conflicts. This has been observed to occur once construction has commenced. Finally, the constructors have to coordinate all of the 2D information produced by the designer and consultants and reassemble all of the 2D information into 3D objects. In the meantime, the designers hopes his/her vision will have been achieved, and the owner wants his/her money's worth. No wonder the owner, designers, and constructors have been prone to have a bad project experience with the unnecessary creation and recreation of information.

In light of the difficulties that have been faced with CAD, the National CAD Standard has defined standards for many aspects of electronic building design data. The standards include: CAD layers, organization of drawing sheets, drawing sheets and schedules, drafting conventions, term and abbreviations, graphic symbols, notations, code conventions, and plotting. Despite the standards that have developed, CAD drawings, considered by some as dumb graphic entities, are characterized by elements of lines, arcs, and circles graphically representing building components. The endpoints, layer, color, and line type are the descriptors of a line. In addition, some CAD versions have a 3D capability and rendering, but it requires a significant amount of time to be invested. Yet, CAD does not include anything about the relevance and meaning of a line because its elements are just data, not information. CAD objects are a representation of highly symbolic information (Baeza and Salazar, 2005). All the meaning has to be inferred by the user otherwise the drawing is useless (Bedrick, 2005). Also, CAD does not contribute easily towards the planning and control of a project (Baeza and Salazar, 2005). All the information the creator used to create the drawing is lost, only to be recreated downstream, yet another contribution to lost time and money.

2.3 Building Information Model

The building information model (BIM) is a fairly new term, coined by Autodesk in 2002, to describe an innovative approach to building design and construction (Rundell & Stowe, 2005). The concept or idea itself is not new to the construction industry because the three-dimensional capability of the BIM has been a dream of the construction industry, and the technology is not new either. For example, three-dimensional programs such as Graphisoft's ArchiCAD have existed for approximately twenty years (Khemlani, 2003). Nevertheless, the BIM is a representation of a building as an integrated database of coordinated, internally consistent and computable information in design and construction. Furthermore, the project information in the model can be material quantities, installation dates, subcontractor responsibilities, and alternative materials.

An important feature of the BIM is the three-dimensional capability. A major benefit of the 3D model is that no training of imagination or prior experience is necessary to visualize a structure from lines and dimensions. Instead, the structure plus a multitude of components, such as rooms, hallway, exits, can be easily viewed and even examined because elements of the BIM are actual simulations of building components; this is a jump from data to information (Bedrick, 2005).

A research study, performed by Kathleen Liston of Stanford University, revealed that paper-based presentations demanded 40% of time spent at project meetings describing the "who, what, where, when, and how" of the project, 20% explaining the rationale of the decisions made, and 30% evaluating goals to be sure project requirements are being met (Sawyer, 2005). Only 10% of time remained for the decision-making phase, where predictive questions like "What happens if we did this?" could be asked and pondered (Sawyer, 2005). Better information delivery through the use of the 3D model, combined with schedule and budget information, could end having to sort through countless papers and increase the productive thinking time to 50%. An added benefit is that alternatives, changes, or adjustments could be discussed at the project meeting without having to return to the topic at another time just to present it.

The 3D feature is beneficial to the construction industry because concepts and ideas can be presented without the need of having previous construction experience, or an understanding of how building components come together. A major issue has always been how to convey an idea or proposal so that another person can visualize and understand it. The BIM has this ability as it can graphically display a building and its sections and components, thus benefiting both the person(s) with the idea and the person(s) receiving it.

In addition, the BIM aids the designer with the design process. Not only is communication clearer, design intent is maintained, quality control is streamlined, and higher analytical tools are more accessible (Davis, 2004). In addition, tasks such as drafting, view coordination, document generation, and schedule creation are automated with the BIM. Finally, the power of computers has been harnessed to enhance the design process instead of mimicking drafting, and the BIM can be transferred downstream to prevent lost time.

Additional research studies of the BIM have focused on the design and construction of a building. The benefits of the BIM are not limited to simply visualization and presentation of information. International construction can be assisted with the BIM as the communication of ideas around the world can occur with less concern for language barriers. One application has been the implementation of the BIM in addressing change orders, which prevents disputes and conflicts of ideas (Mokbel 2003). This study showed that using a 3D parametric building model (BIM) can impact productivity and improve the design process coordination. Another study addressed the impact the BIM has in the construction schedule of a project, such that potential problems are recognized earlier in the process. Despite the advantages and potential applications of the BIM, it is not proper to assume completeness. There has to be continued use of the BIM to further recognize and evaluate any shortcomings of it. Currently, the BIM has assimilated building information, but components such as mechanical, electrical, and plumbing still remain to be fully implemented.

The BIM can facilitate the process of cost estimation. Material and assembly quantities can be extracted directly from the model, and then be fed into a cost database. Traditionally, producing a cost estimate took the builder two to three weeks (Bedrick, 2005). In the meantime, design work continued, and when the estimate was finally given to the architect, the cost estimate could have been rendered inaccurate. The design could have been too expensive, and the building would have to be re-designed. The BIM shortens the time for cost estimating and review to two to three days, which radically increases speed, accuracy, and frequency of estimates. Cost estimates that normally demand two to four weeks to produce because of the manual measurement and calculation can now be produced in a matter of minutes. It is even stipulated that with this setup, the BIM and cost feedbacks can be used to guide design rather than having to fix it with value engineering where reduction of costs often compromises the design (Bedrick, 2005).

In a collaboration between Anshen + Allen architects, Webcor Builders, and Lawrence Berkeley National Laboratory, the architect wanted to analyze the options for the building skin based on cost and thermal performance (Bedrick, 2005). The architect used BIM to develop the deign, which was then directly used by LBNL to apply a simulation program and produce a narrative report in one day instead of the expected fourteen had the architect provided 2D drawings. The architect then tried another option, and LBNL provided a full analysis in two days (See Figure 1). As for Webcor, they used the model to extract quantities and provided a cost comparison in two days instead of 21 days (See Figure 2).

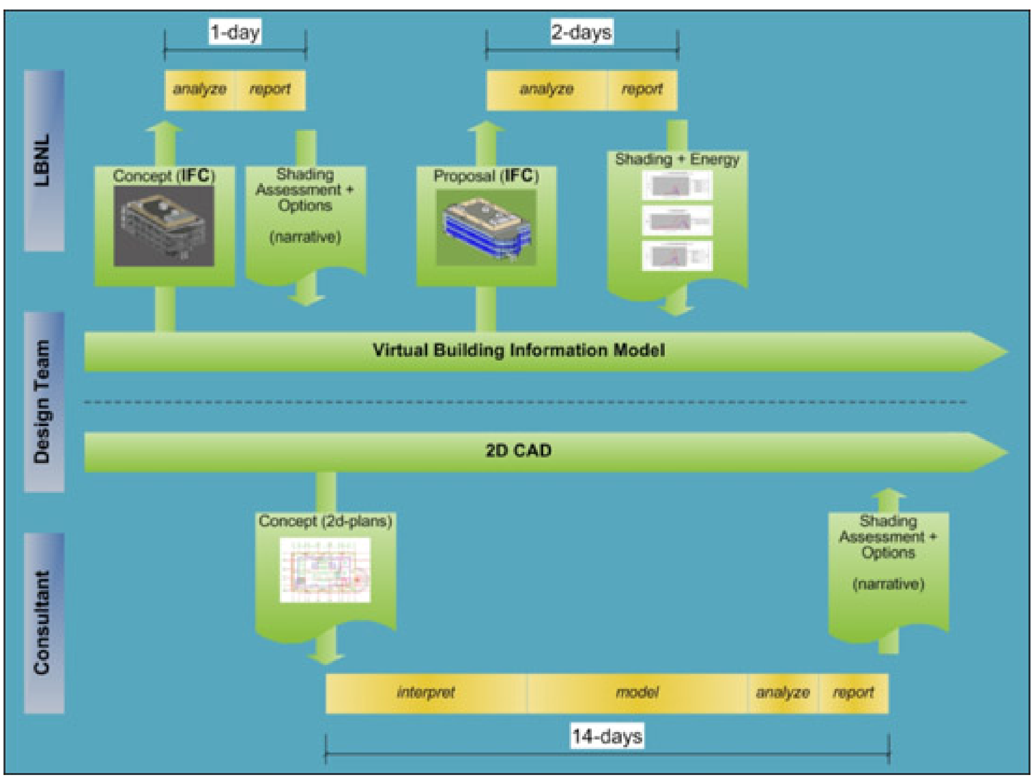

Figure 1: Building Skin Thermal Performance Analysis
(Bedrick, 2005)

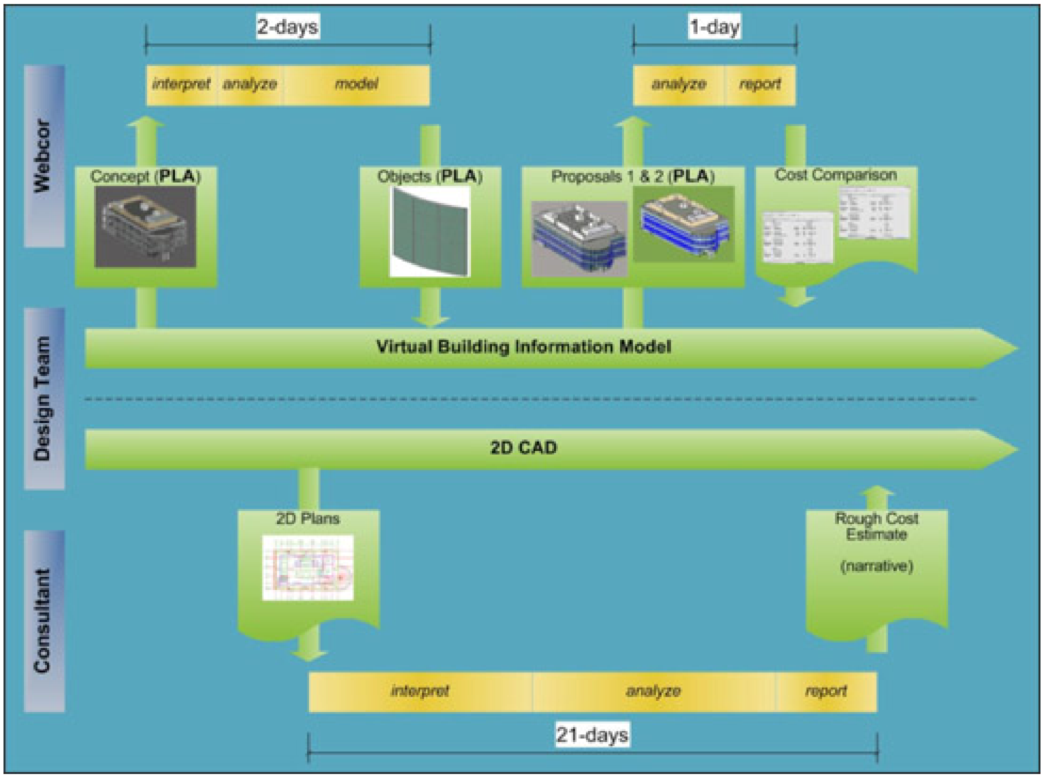

Figure 2: Cost Analysis
(Bedrick, 2005)

In addition to the potential of the BIM being applied in the design and construction phases of a building, the BIM can further enhance the lifecycle operations stage (See Figure 3). The total integration of design, construction, and operations is dependent on the need for interoperability among the countless software programs that are used in the construction industry. The International Alliance for Interoperability (IAI) is an organization promoting effective means of exchanging information across all software platforms by adopting a single building information model. In using the BIM, a greater initial investment will have to be made during the design phase. However, application of the BIM will be significantly cost effective as it will save more money during the construction stage and more notably during the operations stage of a building.

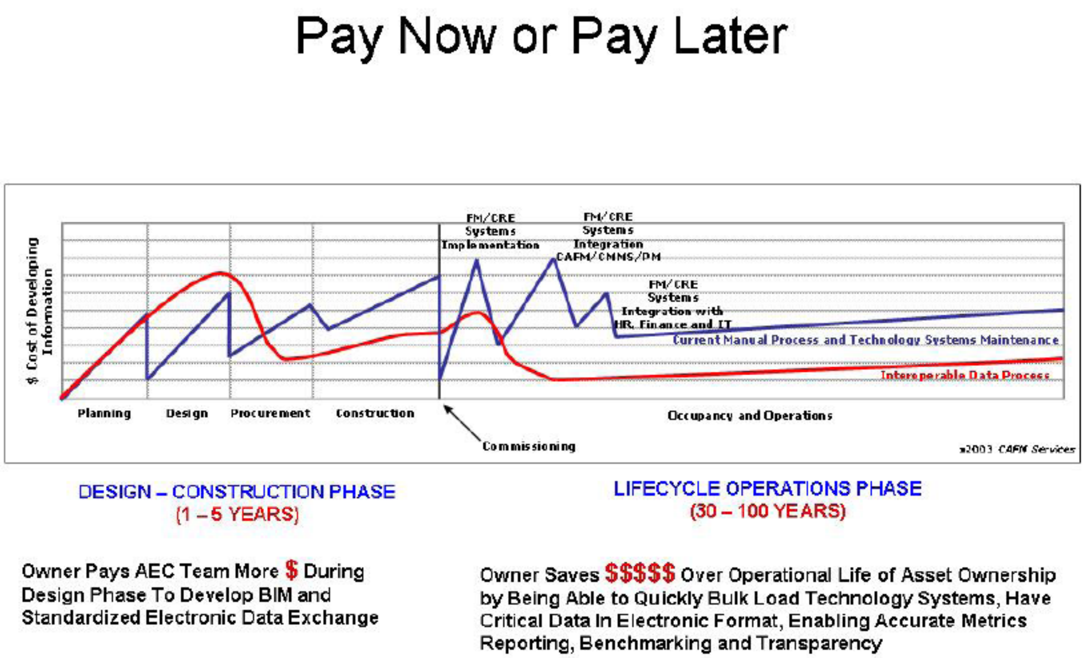

Figure 3: BIM Application
(CAFM Services, 2006)

2.3.1 Parametric Modeling

A fundamental component of the BIM is parametric building modeling. The BIM uses a parametric change engine to automatically coordinate changes and revisions across the project deliverables (Rundell and Stowe, 2005). However, parametric modeling is not an entirely new concept. The manufacturing and mechanical engineering industry has been using Pro/Engineer, a software program with parametric modeling, to design mechanical pieces and components since 1989 (Tse, Wong, and Wong, 2005). Pro/Engineer also has the 3D ability to view a product from all angles. The parametric model in the BIM is somewhat similar to Microsoft Excel, where a change in one cell can automatically be reflected in the entire series of cells (or worksheets) without obligating the user to manually change all related cells to show the new modification in the Excel file. The same concept is found in the BIM where drawings are automatically updated with any applicable changes. Two-dimensional programs such as CAD use coordinate-based geometric models to arrange the information, and do not have an automatic change in the software or in any of the files. On the other hand, BIM programs use a partially constrained model that creates a network of building element relationships, hence, the major difference between the BIM and CAD.

Parametric modeling is an automated process that uses the building element network to keep track of changes. In a modification, the parametric change engine determines and coordinates which other elements need to be updated and how to make the change (Autodesk, 2005). For example, if one section of the drawing is changed or altered, the entire drawing is automatically updated to reflect the change without having the designer/drafter manually applying the change in every part of the drawing. The long-standing two-dimensional AutoCAD does not have this ability to represent the relationship between objects being drawn, thus it demands time and money towards updating drawings. Indeed, CAD has been beneficial, yet it has not fully reaped the benefits of technology because it placed the engineer/drafter in front of a computer instead of a drafting table. In addition, the BIM has the ability to integrate all building component drawings, such as recognizing that wall sections form an enclosed structure.

2.4 Autodesk Revit

Revit was first introduced by the Revit Technology Corporation in 1997 as "Revit software," and then acquired by Autodesk in April of 2002. Revit is similar to CAD in the way that walls and building components are drawn, which is helpful to architects and engineers, but like any other software, it requires a learning curve. Autodesk Revit is one of the few software programs that are capable of producing a building model, along with Graphisoft's ArchiCAD. The great benefit of Revit is not solely the 3D modeling capability, but rather the parametric modeling technology. The parametric technology in Revit offers the ability to architects, engineers, owner/operators, and construction professionals to transform the manner by which buildings are designed, constructed and operated over their lifecycle.

An architect can work with real-world components such as walls, windows, and doors. With AutoCAD, the process of drawing walls, windows, or doors requires multiple steps. A multitude of lines have to be drawn to simply represent a window. The shortened method for this would be making a “block,” which is a combination of lines and colors saved in the software, for example, a window. The window block can then be accessed later in the drawing process and placed in its assigned location. Changes to drawing then have to be made manually to reflect the window’s place in the wall. The parametric feature in Revit does this automatically for the architect, thus ensuring that all drawings and views are always consistent. This also assists in the coordination in the model itself as well as the people involved in the actual project.

Revit has the ability to display various aspects and components of a building. The following are possible building systems (See Figure 4).

Building Systems
Excavation
Footings & Piers
Foundation Slabs, Walls, Columns
Interior Basement
Superstructure
Exterior Closure
Interior Construction
Furnishings

Figure 4: First Tier Building Systems

The first tiers can be organized into subsections, such as the columns, slabs, and stairs found in a building superstructure (See Figure 5).

Superstructure	Furnishings
Columns	Furniture
Floor slab	Desks
Stairs	Chairs
	Equipment
	Lighting
Exterior Closure	**Interior Construction**
Windows	Partitions
Exterior Walls	Doors
Roof	Assembly Description
Specifications	Assembly Code
Assembly Description	Cost
Assembly Code	Description
Cost	Manufacturer
Description	URL
	Type Mark

Figure 5: Second Tier Building Systems

In addition to the building components, the site and elevations can be integrated into the building model, thus displaying real world information about the building and where and how it sits on the project site. This is made possible by the ability to import a CAD drawing into a Revit file. An observed difficulty has been setting comparable scales so that a CAD drawing can be used without having to recreate the drawing or having trouble with setting the proper scale. As previously mentioned for the BIM, Revit has the ability produce 2D floor plans and section views (See Figures 6 and 7) in addition to schedules, and ceiling plans.

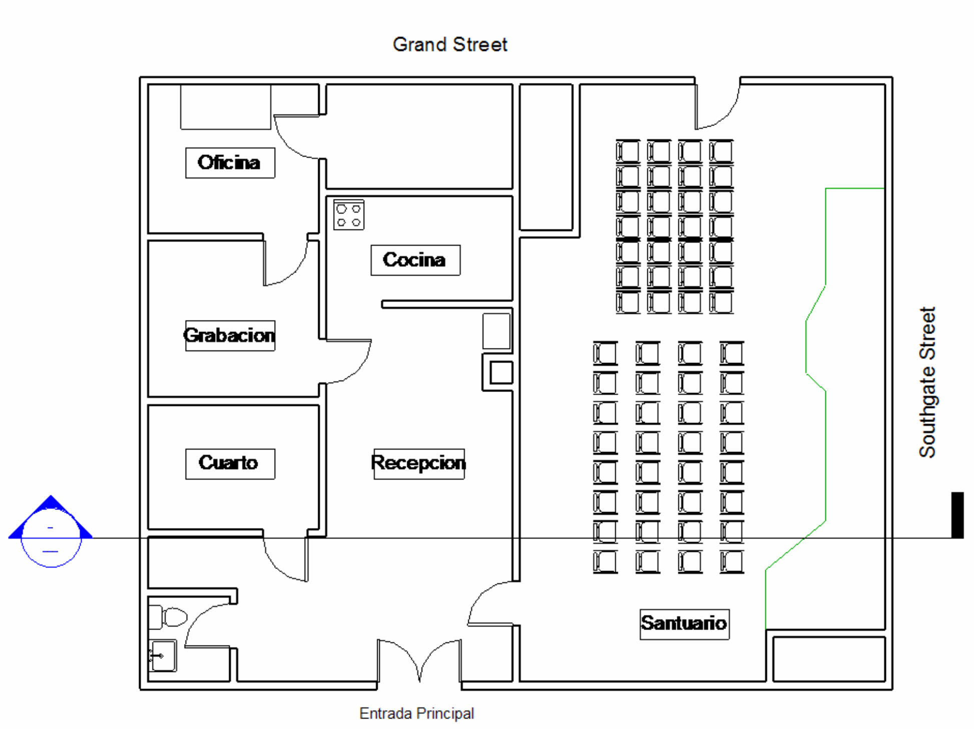

Figure 6: Floor Plan

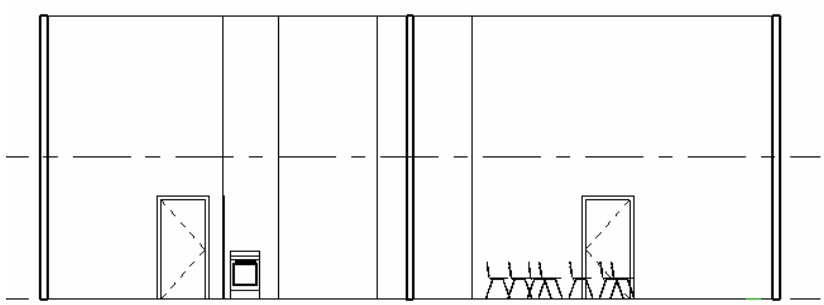

Figure 7: Section of Floor Plan

Autodesk Revit Building mainly focuses on building components. The software does contain some structural components such as metal and timber beams and columns. Autodesk Revit Structure is the 3D structural package, which provides a fully integrated physical and analytical model for structural engineering, analysis, design and documentation (Autodesk, 2006). Autodesk Building Systems has been the long standing software, which is an AutoCAD-based product for the design and construction documentation for the MEP aspect. Autodesk Revit Systems has recently been released, but it was the first version. Integrating these areas would considerably enhance the BIM and perhaps even the project experience.

2.4.1 Autodesk Revit Study

The author of the "Autodesk Revit: Implementation in Practice" white paper conducted a study about the implementation of Revit in ten architectural firms, with sizes ranging from 3 to 700 people (Khemlani, 2004). It was found that most firms expressed a strong liking for it (a number was not specified), in addition most said that it was easy to use, while others stated the opposite. The study also demonstrated that an increase in productivity was experienced, but the time saving was offset by the time needed to learn the applications and customizing the program to suit the needs of the firm. Extra benefits, which at the time of study were not quantifiable, were:

- More time for design
- Better understanding of design
- Better presentation of design concepts to clients
- Reduced fear of making last-minute changes
- Better documentation with less errors
- Less tedium
- More confidence in taking on projects
- Lesser divide between designer and CAD drafter

The study also reported that most firms stated that building owners and clients are not aware of BIM, thus they are not demanding it, nor offering to pay for these services

(Khemlani, 2004). Furthermore, it was noted that Revit implementation in the surveyed architectural firms did not immediately translate into more business.

Obstacles that were found in the study varied from technical to personal. Implementing Revit requires an investment expense, and many still debate whether the software is worth the money. Since the program requires a learning curve, there are fears of having to adjust to a new system as well as the ability to maintain with the project schedule. Surprisingly, one obstacle identified by the study was that the BIM was assumed to be for "standard" designs (standard designs were not specified but it is inferred that it pertains to warehouses, small apartment buildings, and office buildings), and architects considered their own designs to be too unusual, specific, and customized to be modeled with the BIM.

Lastly, Revit requires more collaboration and communication than working with CAD. Due to the fact that Revit can work at the macro and micro levels and most people work at the micro level, the sentiment has been that the level of success and individuality will be diminished (Khemlani, 2004). Also, Revit does not permit missing or conflicting information because everything in the model has to relate. For some project participants, this could be difficult because missing information has been somewhat considered to be in the time buffer that occurs when a project is procured.

2.5 Autodesk Revit Systems

The Autodesk Revit Systems program was recently released (April 2006). The Revit Systems is the much anticipated mechanical, electrical, and plumbing (MEP) engineering package that has been missing from the Revit Building releases, which has focused on the architectural components of a building. This package finally links MEP systems with the building model. This release is by no means a comprehensive collection of valves, pipes, circuits, and ducts because of the immense variety that exists. Yet, Revit Systems is quite extensive with all of the features that it possesses, and like its relatives, key components are the parametric modeling engine and the bidirectional associativity (automatically managing and updating changes in all views). Revit Systems has the potential to minimize coordination errors between MEP engineering design teams, along with architects and structural engineers. For instance, a seemingly common problem in construction has been a duct designed to go through where a structural beam is.

The Revit Systems software features a variety of tools for mechanical, electrical, and plumbing design (Autodesk, 2006).For mechanical, there is a mechanical duct and pipe system modeling that enables the creation of HVAC systems, and built-in calculators that can size mains, branches, and whole systems at a time. The electrical aspect consists of electrical lighting, power circuitry, and electrical lighting calculations. Lighting and power circuitry uses circuits to track loads, number of attached devices, and circuit lengths. Also, wire types, voltage ranges, distribution systems, and demand factors can be defined to ensure compatibility of electrical connections as well as prevent overloads and mismatched voltages. The electrical lighting calculations are based on the zonal cavity method, which can automatically estimate the lighting levels in rooms based on the type of lights placed in the space. Reflectively values can be established in addition to attaching industry-standard Illuminating Engineering Society (IES) data files to lighting and defining the calculation work plane height. As for plumbing, piping can be modeled in accordance to industry code, along with the automatic placement of all risers and drops and invert elevation calculations as the user completes the design.

Others applications of Revit Systems involve the compatibility of it with other programs. Revit Systems can use the architectural spaces made in Revit Building to support load calculations, track airflow in rooms, and coordinate panel schedules. Furthermore, Revit Systems permits the exportation of the building model to gbXML for energy and load analysis. A complete analysis allows the importation of data and storage of the results in the model. For those that do not use Revit Systems, the information can be exported to spreadsheets.

2.6 Building Operations and Maintenance

On a college campus, the purpose of a building is to provide an environment for people to work, learn, and play. In order to make this happen, facilities management is concerned with the life safety as well as the energy efficiency of the building so that it is comfortable and healthy. Life safety primarily refers to fire safety, which is defined by state or municipal building codes. Energy efficiency is not so defined, a good part due to this being a relatively ambiguous area. The perpetual issue for managers has been the cost of supplies and services, and not about standards because no laws setting such limits have been established. However, there have been initiatives to reduce energy consumption, especially in light of increasing energy costs and concerns of impacts on the environment.

According to the United States Department of Energy, addressing O&M considerations can contribute to improve working environments, higher productivity and reduced energy and resource costs (DOE, 2006). In creating an effective O&M program, the DOE recommends that the following procedures be considered:

- Ensure that up-to-date operational procedures and manuals are available.

- Obtain up-to-date documentation on all building systems, including system drawings.
- Implement preventive maintenance programs complete with maintenance schedules and records of all maintenance performed for all building equipment and systems.
- Create a well-trained maintenance staff and offer professional development and training opportunities for each staff member.
- Implement a monitoring program that tracks and documents building systems performance to identify and diagnose potential problems and track the effectiveness of the O&M program. Include cost and performance tracking in this analysis.

Elements that an effective O&M program address are HVAC systems and equipment, indoor air quality systems and equipment, cleaning equipment and products, materials, water fixtures and systems, waste systems, and landscape maintenance (DOE, 2006).

2.7 WPI Plant Services

The mission of the Plant Services Department is to provide a safe, clean, properly maintained environment for the WPI community, in support of academic and social activities (WPI website). Plant Services is the party responsible for the operation and maintenance of the 43 buildings on the WPI campus, in addition to the construction and management of new campus buildings. Areas of responsibility for Plant Services include custodial services, grounds services, trades maintenance and repairs, building projects and renovations, and environment and occupational safety.

However, the areas of most concern are heating and electrical, as these are more prone to needing routine maintenance. Another item of concern is the consistency of building components. Plant Services wishes to install common building components, such as lighting fixtures, among the campus buildings because of the need for similarity and continuity in the system. This is because some manufacturers, say of lighting fixtures, may go bankrupt and when a replacement is need, it is very difficult, if not impossible, to obtain. The department is directed by John Miller, and then organized into multiple divisions, such as custodial and technical trades (See Figure 8).

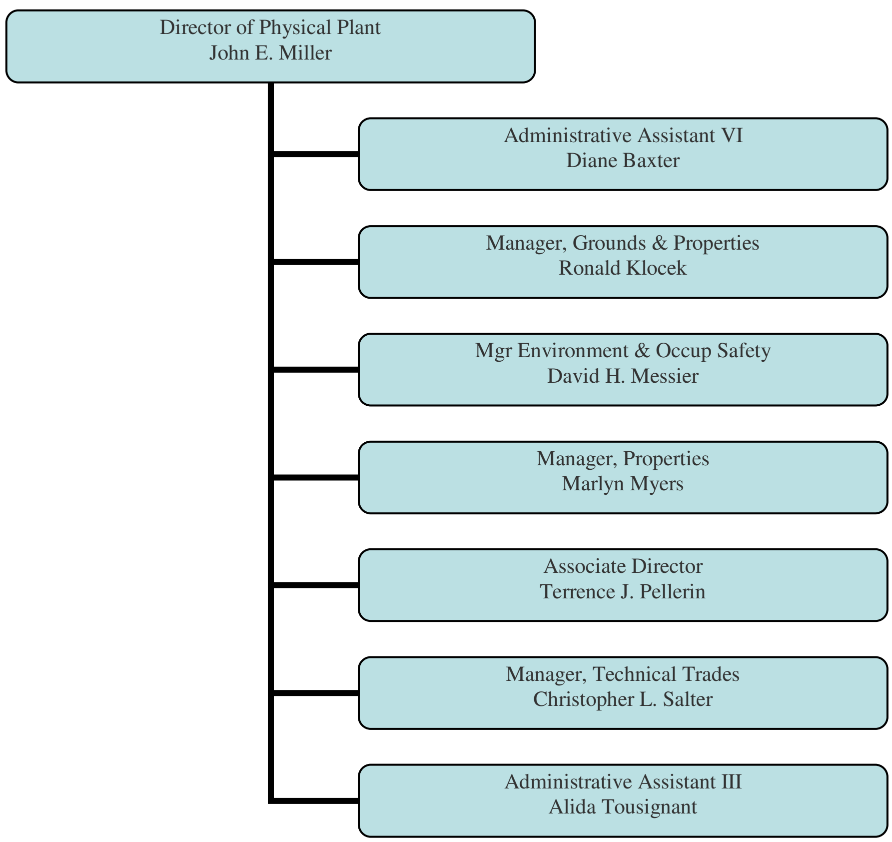

Figure 8: WPI Plant Services Organizational Chart

2.7.1 Current Information Management

The current information management system of building information of Plant Services is a library of books, papers, drawings, floppy discs, and compact discs located in the department office of Plant Services. The drawings are plans and sections of all buildings on the WPI campus as well as site plans. Recently with the construction and completion of the Campus Center in 2001, the amount of information obtained by the contractor has increased substantially (Miller, 2005). The Campus Center is a three story building, which accommodates a multipurpose room, multiple meeting rooms, a food court, administrative and student offices, and a bookstore.

The handover of the Campus Center consisted of several binders, plans, and discs. The binders were general conditions for construction divisions 1-16, and maintenance manuals. Cutler Associates, the construction manager, submitted twelve binders to Plant Services. There were equipment and systems maintenance manuals for food services equipment, electrical, fire alarm system, fire protection, HVAC, and plumbing. Another binder was included containing information about the warranties provided. Plant Services speculates that the amount of submittals about the Bartlett Center provided by Gilbane will be the same to that of the Campus Center despite the substantially smaller size and more limited use of the Bartlett Center. The James Bartlett Center has recently been completed (May 2006). Construction commenced in March 2005, under the management of Gilbane. Once completed, the Office of Admissions (for undergraduate admissions) and the Office of Financial Aid will be the primary users of the Bartlett Center, but the ultimate responsibility of maintaining the building will lie with Plant Services. The handover of the Bartlett Center will consist of two copies of manuals, warranties, maintenance contracts, a record project manual, and four copies of the final site survey and test reports and inspections, as specified by the project contract. According to the Christopher Salter, Associate Director, the number of submittals obtained by the builder varies, depending on the type of project. It ranges from two to four copies, which are then stored in the library of the Plant Services main office and in the trade shops.

An interesting point was that the discs containing information about the Campus Center were virtually useless because they contained CAD files. CAD is not used in Plant Services, so it is also practically non-existent in the department. This highlights the fact the Plant Services is not a technologically advanced department. The warranties provided generally expired a year after the date of substantial completion. Unless someone keeps abreast of the warranty information, Plant Services generally is not aware of a warranty's expiration date. Consequences of warranty expiration would be not having the ability to have the contractor or construction manager repair or replace specified equipment at no cost to the owner.

The maintenance manuals are a collection of information available for those who need it, but it seems to require setting aside time to access the information. The manuals contain information such as specifications, type, manufacturer, catalog number, ordering information, installation, dimensions, features, and a general description of the component. For instance, an electrician must review the electrical system binder in order to obtain information about the installation guidelines, and product specifications. Some electricians, and other trade specialties, will not go through this process mainly because it takes time and the process is too tedious (Miller, 2005). It was undetermined whether or not an interested person would always find the necessary information by browsing through the books.

2.7.2 Fire Safety

Another topic of interest (or concern) to Plant Services is fire safety and code compliancy. Justifiably, there is an inherent obligation to provide a safe environment. In addition, there are standards that must be met, these standards being set by the building inspector and the fire marshal. Fire safety is not simply the performance of the building itself in case of a fire, but more so the passive and active measures that exist. Passive measures are doors, walls, corridors, exits, emergency lights and building materials. Active measures are actions that directly combat the spread of a fire, such as sprinklers, fire extinguishers, and alarm systems. Code compliance is vital to a building; otherwise, the certificate of occupation is not authorized.

The fire protection and safety system of WPI consists of fire extinguishers, specified fire extinguisher labels, illuminated building exit signs, emergency lighting, and sprinkler systems. Fire extinguishers are categorized by fire hazards, which are A, B, C, D, and K class. Class A extinguishers are for fires caused by wood, paper, and clothes. Class B is for fires caused by flammable liquids such as gasoline and oils. Class C extinguishers are to be used on burning electrical equipment, Class D for use on combustible materials, and Class K extinguishers are for extinguishing kitchen grease fires. Most of this information was gathered over time by Interactive Qualifying Projects (IQPs) at WPI.

One such IQP was titled “E-Buildings, An Information System for Facilities Management on the WPI Campus,” was conducted during the 2004-2005 academic year. This IQP developed of 3D models of eight academic buildings on WPI with Autodesk Revit. The IQP then focused on two buildings to explore fire safety at WPI, highlighting the manual recording keeping and inspection process conducted by Plant Services.

The IQP implemented Autodesk Revit in the organization of fire safety information. It was found that the traditional management of information was rudimentary at best (Brault, Krol, and Molineaux, 2005). Plant Services hires contractors to map and inspect the safety equipment to determine whether it is code compliant. However, there is no all-compassing location map displaying the entire safety equipment system. The maps are paper-based which are easily updateable, and changes to the maps require that a new set of documents be produced. Research performed at WPI explored the integration of three dimensional parametric building model with geographic information systems in educational facilities planning and management (Samdadia, 2004). A database was developed that graphically related the database with the physical location of information pertaining to fire safety.

3.0 Methodology

The methodology used in conducting this research consisted of literature review, interviews, and a case study.

3.1 Literature Review

A literature review was conducted to develop an understanding of the subject. The goal was to gain a comprehensive understanding of the BIM, parametric modeling, construction industry fragmentation, and issues about operations and maintenance of a building. Having once accomplished this, it was then made possible to consider what applications of the BIM have and are being considered. The literature that was reviewed consisted of white papers, journals, and other publications.

3.2 Interviews

Two members of WPI Plant Services were interviewed. They were John Miller, Director of Plant Services, and Christopher Salter, Associate Director, Technical Trades. The interviews served to verify that issues considered relevant during the literature review were similar, if not identical, to the issues that Plant Services considered important for the operations and maintenance of a building. In addition, the interviews served to research the current practice of information management by the Plant Services department. The interviews also provided an opportunity to identify new issues that were not identified during the literature review.

3.3 Case Study

A case study was chosen to conduct research relevant to the development of this research. The case study is the James Bartlett Center. The James Bartlett Center, or

Bartlett Center as it is commonly called, was chosen because it was being constructed on the Worcester Polytechnic Institute campus during this research. Using the Bartlett Center also offered the ability to work with Plant Services, and Plant Services providing readily available information. Construction of the Bartlett Center commenced in March 2005, and was scheduled to be complete in May 2006. Once completed, the Bartlett Center will house the Office of Admissions and the Office of Financial Aid. Another reason for the choosing of this project was the potential seen in using the BIM for the benefit of the Department of Plant Services of WPI.

Given that Plant Services would be responsible for the building, it was considered that there was an opportunity to use the building information model for Bartlett Center, but more specifically directed towards the operations and maintenance aspect of the building, instead of design and construction, which is an area that has been researched. As previously mentioned, the current practice of building information management in Plant Services is storing building information in the department library and trade shops. When information about the building or about a building component is desired, ideally, a person must first identify the building component by locating it in the building and then conduct some research of the component at the Plant Services library located in the Plant Services main office.

The case study consisted of developing a 3D model of the Bartlett Center utilizing Autodesk Revit. The Revit model was developed by three graduate students participating in an evening graduate class (Hoey, Martino, and Szafarowicz). The 3D model was developed using Autodesk Revit version 8.1 because Revit is a software program readily provided by the WPI Civil & Environmental Engineering Department, and the convenience of not having to purchase the software. In addition, Revit is introduced in some courses offered at WPI, thus the availability of the software program. The Revit model was produced based on the plans obtained from Gilbane, the construction manager of the Bartlett Center project. In addition to the graduate student group, a Major Qualifying Project (MQP) group provided insight on the Bartlett Center (Basha, O'Hearn, and Rathbun). The MQP group attended project meetings of the Bartlett Center on a weekly basis since August 2005 to keep track of any changes. The goal of the MQP group was to analyze the usage of the attic space and propose potential uses of the space in the future taking into account such subjects as structural performance, cost, and constructability. The MQP group also developed at model of the Bartlett Center utilizing Revit.

In addition to the plans obtained by Gilbane and the input gained from the MQP group, an interview was established with the project manager of the Bartlett project, Henry McNeil Benner. The interview served to discuss the documentation and submittals required by the project contract between WPI and Gilbane. Also, the interview provided information on what and how Gilbane would provide to WPI once the building is completed.

Once the Revit model was completed, it was then possible to make use of the Revit software ability to export DWF files in 2D and 3D. Utilizing the DWF files was more manageable because of the smaller file size. The DWF files can also be uploaded onto the Internet, making the models accessible. Doing so makes the drawing readily available without requiring the user having to learn how to use Revit.

3.4 E-Buildings Interactive Qualifying Projects

Ongoing research at WPI is being conducted with the "E-Buildings" Interactive Qualifying Project (IQP) series. An IQP is work completed by a project team relating science and technology to society. The E-Buildings series has attempted to make building information readily accessible and manageable for implementation by Plant Services. The first IQP of the E-buildings series was conducted during the 2003-2004 academic year. Titled "Safety on the WPI Campus," the project developed an information system to manage fire-safety equipment data on the WPI campus (Go andPhillipps, 2004). As it was intended to modernize the record keeping process of Plant Services, CAD drawings for five academic buildings were updated with symbols indicating the location of safety equipment on the campus map. Fire code compliance was also evaluated.

The second IQP, titled "E-Buildings, An Information System for Facilities Management on the WPI Campus," was conducted during the 2004-2005 academic year (Brault, Krol, and Molineaux, 2005). This IQP was somewhat similar to the first one; the major difference lied in that 3D models were furnished of eight academic buildings on the WPI main campus using Autodesk Revit. Further work was then limited to two buildings in the intent to explore fire safety at WPI, highlighting the manual recording keeping and inspection process conducted by Plant Services.

The third, and currently ongoing, IQP is titled "An Integrated Building Management System for the WPI Campus," which focuses on the creation of a web based information system for Plant Services to help make decisions related to the safety and efficient operations on WPI buildings (Mills and Halilaj, 2006). They are currently validating a prototype building information system while also analyzing the suitability of the existing data with respect to the requirements of the system by maintainers and managers of buildings. The basis of the IQP was input by various entities that would be interested and/or involved in the status of a building, particularly fire safety. Upon completion, this latest IQP will provide information on Goddard Hall and the location of hazardous materials, fire extinguishers, and fire alarms via the Internet for use by Plant Services as well as the Worcester fire department and building inspectors.

3.5 Outreach to the Industry

The gathering of information from the construction industry consisted of contacting various physical plant/facilities management offices of colleges and universities in the Worcester area. The reasoning was that this research was primarily applied towards the operation and maintenance of a new building (the Bartlett Center) on a college campus (WPI). In the effort to maintain some sort of similarity, it was decided to obtain information regarding the practices employed by other colleges and universities in the Worcester area. It was also practical because many of the colleges and universities in the Worcester area had some form of new building construction since the year 2000. Another benefit of these colleges and universities was that their campus size did not differ drastically from that of the WPI main campus, it was either slightly smaller or slightly larger. A substantially larger campus would probably have had a management program different to that of WPI.

Six colleges and universities were contacted to obtain information regarding the practices and concerns of building management. Four of the six institutions responded. The institutions were identified as University A, B, and so on instead of by their official names. University A, of Worcester, has a science center that recently opened, having been in operation for slightly over a year. University B, of Worcester, has a parking garage and residence hall that opened in 2002 and 2003 respectively. University C, of Worcester, had parking garage and a science center open in 2001 and 2003 respectively. University D, of Worcester, had a science and technology center open in 2001 as well as a residence hall in 2005. By consulting these institutions, data was gathered about their respective departments and the information storage procedures.

The interviews with these institutions were primarily focused on what was demanded or requested when the newly constructed building had been handed over to the institution. In addition, the interviews served to obtain information as to whether the submittals provided by the builder were satisfactory and if anything else is desired. Furthermore, the interviews served as an opportunity to further view what issues about building O&M were being faced on academic campuses. An additional question was about the view on using information technology in their respective departments and what impact, if any, it would have. The interviews were carried out over the phone and/or in person instead of web surveys because of ability to clarify any terms the interviewees used and discuss ideas or concerns.

4.0 Survey of Facilities Management Personnel

The purpose of the survey was to gather information that extended beyond the Bartlett Center case study and information management practices of Worcester Polytechnic Institute. The information gathered was about the building operation and maintenance procedures, feasibility, the application of information technology, and any concerns and opinions regarding information technology at other academic/collegiate institutions.

It was found that all the collegiate physical plant departments interviewed maintained their building records and building information in paper form in some sort of library. In addition, no steps have been taken by any of the institutions to digitize the respective information. Documents in paper form were desired because of paper's practicality and dependability. It was also because such documents in said form were given to the institutions by the construction firms/companies as specified in the construction contracts. There was a general sense that paper was essential to the way building management was carried out. By no means does the application of the BIM in the operation stage of a building signify a complete substitution of paper, but rather as another tool to enhance the owner's ability to maintain and efficiently use the building information that has been generated and passed down. The role and benefits of paper are not intended to be questioned, and it is considered to be aside from this research, thus no discussion about the role and uses of paper.

4.1 University A

University A is an academic institution that opened a science center on its campus of approximately fifty buildings. University A demonstrated some interest in the application of information technology in the department's information management. The current method of storing and using building information is very much similar to that of WPI. Binders and plans are used to organize and display information. The set of documents are obtained from the builder, according to the construction contract, in addition to the department requesting what it wants. The set of documents are stored in the department's office, and are available to anyone who needs it. A difference between University A and WPI is that University A requests three sets of as-builts and operations & maintenance (O&M) manuals from the builder, while WPI requests varying amounts. One set is kept at the previously mentioned department office, while a second set is stored at the preventative manual shop, which consists of areas such as lighting and elevator systems. The third set is kept at the electrical shops.

The aforementioned shops are what seem to be more accessible to the various trades, where electricians, plumbers, and other tradesmen can access the information without having to go to the department office. This is interesting because it gives the department a sense of versatility. On the other hand, the use of different locations may complicate the accuracy of the information that is available. Although three locations are not a large number of locations to keep track of, it does still pose a degree of difficulty. Theoretically, revisions and edits made to the information, for instance a binder, might not be included. Of course, the tradesman may simply just have to call or check with other people.

University A also obtained all of the job records regarding its most recent project. The job records comprised of correspondence, minutes, application for payments, change orders, emails throughout all phases (from start to finish), and CAD drawings in digital form. There was no indication that all of the documents were constantly used, more so as a reference when it was necessary. It was stated that CAD drawings were also not used at all. Even if the CAD drawings were final submittals, the department did not intend on using or referring to the drawings. Much like WPI, the reasons were the same that CAD was not used throughout the department, instead there was a preference for the paper form of the drawings.

For University A, the construction of a new science building required training. The new building was a LEEDS certified project, and some of the components were elaborate. It was stated that just the electrical section of the three binders provided to University A were each six inches thick. In light of the complexity of the building, preventative maintenance programs had to be developed for it. The preventative maintenance program, much of it based on the received training, requires certain actions to be done regularly.

Additionally, it was discovered that University A manually keeps track of the warranty information of its buildings. It was stated that the warranties are used as necessary. There was no elaborate method to keeping track of the warranty information, it was just done so. It was also stated that University A gets what it wants from the contractor/manager because it "sets the process," meaning, they establish the rules and obligations. This last statement is of interest because it seems somewhat antagonistic against the builder. Rightfully so, the owner (client) should receive all of the necessary and desired information of the building, but it is as if the builder is hiding something and is forced to comply instead of the builder wanting to provide the owner with everything possible. Lastly, the general view of applying information technology was considered to be potentially helpful and even desirable because it would address the issues of time, money, and personnel. Of course, information technology requires that someone be responsible for the accuracy of the information. University A also did not express concerns about the use information technology and how tradesmen might be affected by it. Indeed, there is a slight learning curve, but it was not considered to be a concern. University A was one of two academic institutions that viewed information technology in an optimistic manner.

4.2 University B

University B is an academic institution that recently opened a residence hall and a parking garage on its campus of over 30 buildings. The current information management practice is paper based. Submittals obtained by the builder are as-builts, operations & maintenance manuals, training if applicable, and plans in the CAD format. The manuals are in binder form. Three sets of the submittals are usually received by the builder, and then stored in various locations. One set is stored in the plan room, which is the department's library. A second set is given to the mechanical and electrical shops, and the last is stored at the general trades shop. Once again, this is where the information is made accessible by placing multiple copies at different locations instead of storing it in one location.

The interview also revealed that University B dedicates time to understand the material that has been given to them. When asked about the amount of time needed, it was stated that a day is needed to sort through the information and gain some understanding of where specific items are located. Having reviewed the submittals, the facilities department of University B will get back to the information from time to time, essentially as needed. This act of reading the information when needed seems reasonable. In academic institutions there is a focus on what work that needs to be accomplished on a short term basis. Custodians and tradesmen will generally do what is needed at the current moment, such as HVAC, which is the area that requires the most attention and work. Long term work is considered to be projects which tend to get accomplished over the summer when activity and usage of facilities is significantly low.

When asked about anything else the department would like from the builder, University B stated that they would also like to receive an architectural as-built to go along with the Request for Informations (RFIs). An RFI simply documents what happened at a certain point of time in a project, and architectural as-built would help to illustrate the RFI. Obtaining such as-built drawings will have to be paid for by the building owner because it is not an industry standard. This is arguably a strong point because usually unless a building owner specifically requests something, it will not be likely that a builder will provide the requested item. For example, in 2005 the United States General Services Administration (GSA) set a goal to have all national office concept reviews on projects receiving design funding in the year 2006 and beyond be supported by the BIM. It is also encouraged 3D object models and other BIM software be used by project teams during the planning, design, construction, and handover to space management and facility operations and maintenance.

The overall opinion of information technology use in building maintenance was not very optimistic. This was founded on the role and use of paper documents, specifically that paper is more reliable in future years. A concern was the ability to use the media on which the information was stored in. For instance, a few years ago, the choice was floppy disks, which then became compact discs, and could potentially become USB drives in the future. In regards to paper, it was preferable because one can go back to the paper documents 10 or 15 years later and read the information, something that could be difficult in digital storage devices. This concern is well founded because it brings up the topic of longevity. The idea is that the information can be read even a hundred years later. As previously mentioned, the role of paper is not being contested, but rather if the information can be digitalized as another tool to use. Indeed, as University B stated, a paper backup will be needed. When asked about space, the response was that space is always an issue and it is addressed when needed. In addition, it was stated that using information technology depended on if the architect was willing to use it. The architect using information technology seems promising, yet as stated before, it might require the owner to request such a thing. On the other hand, the architect could use information technology to display his/her ideas and enhance the project experience for all of the project participants.

4.3 University C

University C is an academic institution that recently opened a science center and a parking garage on its campus of over 40 buildings. Its paper based information is stored on shelves and bookcases in its department's office library. Like other schools, University C obtains as-builts, operation & maintenance manuals, and any applicable training. Two sets of drawing and manuals and sometimes four, depending on the contract arrangement, are obtained by the builder. In addition, it was not stated whether any other items were desired by University C for the builder to submit to make building care easier. The sets are then distributed to different locations in the institution, one set at the department office and another at the trades shops or mechanical shops, depending on the type of work involved.

University C also hires an outside company to manage some of its maintenance information. The information outsourced is limited to Standard Operating Procedures (SOP), which are made available as online booklets. No other information is posted online despite the opportunity to use the online forum. This led to asking about the effect of using information technology to store and display building information. The response was that it would be helpful because of the availability and accessibility, but it would require education. It was expressed that most mechanics do not want to be bothered to have to learn how to use a program to access the desired information. Even if manuals were posted online, it was felt that it all goes back to paper. Depending on the type of work to be completed, whether mechanical or electrical, it was stated that there is a need to see the whole picture on a C or D print because of the difficulty that would exist if it were to be done on a computer screen.

Another concern expressed was the validity of the database. It was considered that the database needs to updated, which could be constant work, and be compatible with other software. In addition, it was thought that the ability to support such a database might also depend on the computer/network department of the institution.

4.4 University D

University D is an academic institution that recently opened a residence hall and a science & technology center on its campus of approximately 20 buildings. In its recent capital projects, the university received as-built drawings of the floor plans and MEP areas, operation & maintenance manuals, and warranty information. There were no additional items that were desired to be received from the builder because the university also specifies what it wants from the builder. The as-builts were specified to be all final versions, and any in-progress ones were unacceptable. The manuals were for every piece of equipment such as diesel generators, rooftop unit ventilators, and filters. The warranty information entails everything from the building envelope in, for labor and equipment. As for keeping abreast with the information, the institution simply has to check the information on occasion.

The information is kept in the department library as well as the technical shops. University D is also in the process of establishing five separate locations containing the drawings, O&M manuals, and warranty information of a building. An additional practice is placing a copy of an O&M manual near its respective item of equipment. This practice seems practical because it decreases the need for personnel to have to search for any desired information in a stack or shelf of binders. An individual can go to where the equipment is located and find the information readily at hand. Common jobs for the facilities department of University D were elevators, doors & hardware, plumbing, painting, and preventative maintenance especially for life safety equipment such fire alarms, sprinklers, and emergency lighting which are supposed to be checked annually. It was stated that electrical work is the least common job performed.

As for getting oriented with the information submitted by the builder, University D obtains the construction and design documents and gives them to the various trades of the university at the beginning of the project. The intent is that the personnel who will eventually be involved are knowledgeable about the placement and arrangement of the building and its various components. The practice has also served as a means to identify problem areas that would make difficult the work to be completed by the tradesmen once the building has been finished. A supporting reason, and justifiably so, was that the practice of just receiving the keys from the builder at the end of the project was a costly thing to do, and it would be better to review the design documents as a preventive measure. It was also stated that third-party commissioning was another option, which helps to go through the various building components and identify problems.

The overall outlook on information technology was positive, considering it has the potential to make building maintenance, specifically preventative maintenance, safer and faster. Safer because people are expose to less danger, and it would help in the process of making information accessible and available to those who need it. In addition, University D considered that information technology would save space, as well as provide a backup. An example presented was a building that burned which contained all of the records of building information on a school campus, thus being lost forever. The application of information technology also provides the ability to make additional copies of building information.

Additional thoughts about using information technology were included putting digital photographs in the database because it could help identifying equipment and components. Also, it was desired that a bridge between a work order system and the building information database be created. Currently, facilities management software such as Archibus and School Dude seem to offer that service, but it is also a matter of the cost of the program. Another thought about information technology was the potential of its use in obtaining the temporary and final certificates of occupancy, where such items such as maintenance manuals, mechanical systems information like fire protection, and warranty reports can be posted.

4.7 State Building Inspector

Per suggestion by University D, an interview with a state building inspector was conducted because of the possibility of the BIM being extended into the certificate of occupancy process. The interview with a state building inspector shed light on various aspects of the certificate process. The building inspector provided a list of items that he asks for before he inspects a building, ranging from progress schedule to the certificate of final completion, and most significantly, a building data summary sheet.

Prior to inspecting a building to issue the temporary certificate of occupancy, the inspector asks for the Request For Information log, Submittal Log, and Proposed Change Order Log. Examining these records allows the inspector to identify and determine what areas of the building have been of concern throughout the construction process so when the inspection is conducted, the inspector can pay closer attention to these areas. Additional documents that are asked to be submitted are the fire protection equipment test reports, structural test reports, structural peer review reports (if applicable), HVAC/Energy code reports, as-built drawings, and designers affidavits. Of the reports and documents about the building, perhaps the most important to the building inspector is the building data summary sheet, which summarizes all pertinent information presented in the various reports.

The summary sheet serves as a synopsis for the building inspector because of the nature of the report being clarity and brevity. It was stated that the summary sheet was created in an effort to present concise information of that found in the reports. Personal experience shows the value of the summary sheet because it highlights information found in the various reports which can be many pages in length. Issuance of the final certificate of occupancy has fewer requirements than the temporary certificate. The only two requirements are the certificate of final completion and the warranty inspection report. It is highly suggested that equipment operation manuals be obtained by the building owner once the certificate has been issued.

The BIM could be utilized to store the information required for obtaining the certificates of occupancy. A building inspector could refer to the information database where the previously mentioned reports and documents would be stored. According to the interviewed building inspector, the summary sheet would be valuable because it presents such information as building classification, fire protection, usage, materials, structural performance, and MEP components. It was stated that once a building is categorized as any of the type listed in the Massachusetts Building Code, most of the building information can be inferred such as usage. Arguably, it could depend on the building inspector with regards to what form the documents are preferred to be read in, either paper or on a computer screen. Nevertheless, the information is made accessible to the inspector before visiting the site. In addition, edits to the BIM could be easier because if a report is changed, the BIM can be edited unlike a paper copy which could be edited, but would require that the copy be updated as well as any other copy.

One concern that arises is that of user friendliness of the database (BIM) for the building inspector. Requiring an inspector to have to learn how to use the software might not be well received. This question was presented to the building inspector who believed that it would not really make a difference in the way an inspection was completed, but it would present some valuable information to the inspector as well as the owner. An option would be using Internet based communications systems that some companies already use for the construction process. These communications systems store drawings and various submittals online, accessible by those who have permission or a password. Extending the communications systems to include the various reports and documents should be feasible. In addition, the posting of manuals and reports could provide more of what an owner desires to receive from the builder, which was expressed by three of the universities interviewed. Providing the owner with more information was also a goal expressed by Gilbane, the construction manager of the Bartlett Center.

4.8 Summary

The interviews conducted with WPI and the four other academic institutions revealed a number of things. One, three of the five schools felt the benefits of information technology might be troublesome to obtain and not be worth the time and effort. The remaining two schools felt that it has the potential to make a difference in the way information is accessed and made available because of the ability to save time and money, and even further protect the well being of the people involved, primarily tradesmen. (See Figure 9)

Institution	Will it change information management?
A	Yes
B	No, paper is preferred
C	No, it demands more work
D	Yes
WPI	No, it will be more trouble than it's worth

Figure 9: Information Management Impact

Arguably, it could be said that the most of the building owner and managers believe that information technology will not make a difference to how information is managed and even used. They may see the benefit of information technology, but also believe that the potential gain is not worth the effort or time that needs to be invested. There is also a concern of how it affects the tradesmen and how they complete their work, particularly in that information technology would be more of an inconvenience instead of an asset. In consulting with the Gilbane project manager of the Bartlett Center, the project manager believed information technology would make a difference not only in how the owner receives documentation, but even in how the industry and companies such as Gilbane do their work.

Of the five universities used in this study, A through D and WPI, 2 universities stated that they would like additional information aside from the submittals they normally receive as specified by the project contract. (See Figure 10)

Institution	Received what is desired?
A	Yes, but need to ask for it
B	No
C	Yes, but need to ask for it
D	Yes, but need to ask for it
WPI	No

Figure 10: Submittal Satisfaction

An architectural as-built was expressed by University B, and WPI would like more extensive as-builts of the subsystems such as the fire alarm system. The other three schools did not express needing or wanting any other submittal from the builder than those stated in the contract, but it has to be stated in the agreement/contract or asked for.

It was also found that there is preference for paper documents because of the dependability of paper and the ability to read the entire documents. The concerns are justifiable since it was also expressed that having to learn computer software might be difficult or inconvenient for those who need the information. As stated, the intent was find out how much information can be stored and accessed digitally with the BIM for the use of facilities managers. The role of paper is not being challenged, but as was highlighted in an interview, when the paper versions of building information are lost, those are generally gone for good. Information technology is yet another means and tool for facilities management office to organize and present needed information in a quick and effective manner. Hence, the proposal to use information technology in addition to paper documents for the building operation and maintenance.

Since it was found that implementing the BIM had mixed reviews because of ease of use and accessibility, the next question was how to gain acceptance of the BIM by most, if not all, facilities management departments as a useful and powerful tool in the operations and maintenance stage. In this research, Autodesk Revit was used as the program to support the BIM. The concern is that Revit is not widely used. Furthermore, CAD is of little use in facilities management departments. In order to benefit from the BIM, software that supports it is needed, which seems unlikely. Yet, the Internet is a widely used medium to research, post, and store information. Programs such as Revit have the ability to export files which can be stored and viewed online. Therefore, it was considered that a prototype website needed to be developed to overcome the resistance to the BIM, and still be useful for the operation and maintenance phase of a building.

5.0 Proposed Case Study Website

A website for the Bartlett Center was developed with the assistance of two students. The website was to contain the three dimensional Revit model and a sample of operation and maintenance manuals, submittals, and warranties (See Figure 11).

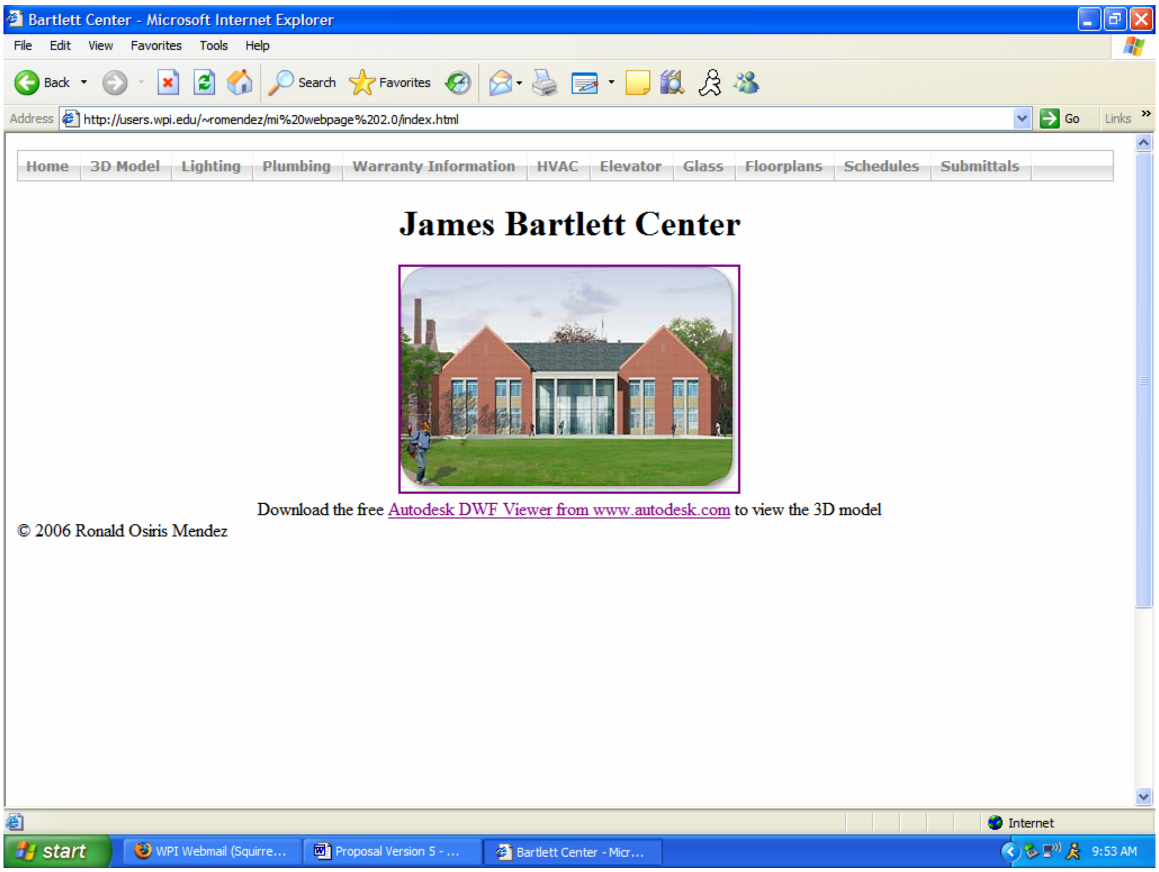

Figure 11: Prototype Bartlett Center Website

The prototype website was to present the building information using the three dimensional Revit model and the Adobe PDF files of the various manuals, guides, and instructions. The documents were arranged according to their respective categories: lighting, plumbing, warranty information, HVAC, elevator, and glass. Floor plans of the first and second floor were included. Schedules of curtain wall mullion, curtain wall panel, door, window, structural beam bracing, structural framing, walls, and the final project schedule were also posted. Submittals were also included as on option, but this was after the website was presented to Plant Services once, and they suggested that submittals are another item that could be added.

The Bartlett Center case study used the Revit model developed by three graduate students participating in an evening graduate class offered at WPI. At the time of this writing, Revit Systems had not as of yet been released, thus the Bartlett BIM not including any information about the building’s mechanical, electrical, or plumbing components. It was also of interest at the time that the inclusion of building information was limited to the architectural components. Once the Bartlett BIM was generated, DWF files were produced and exported from the Autodesk Revit software (See Figure 12).

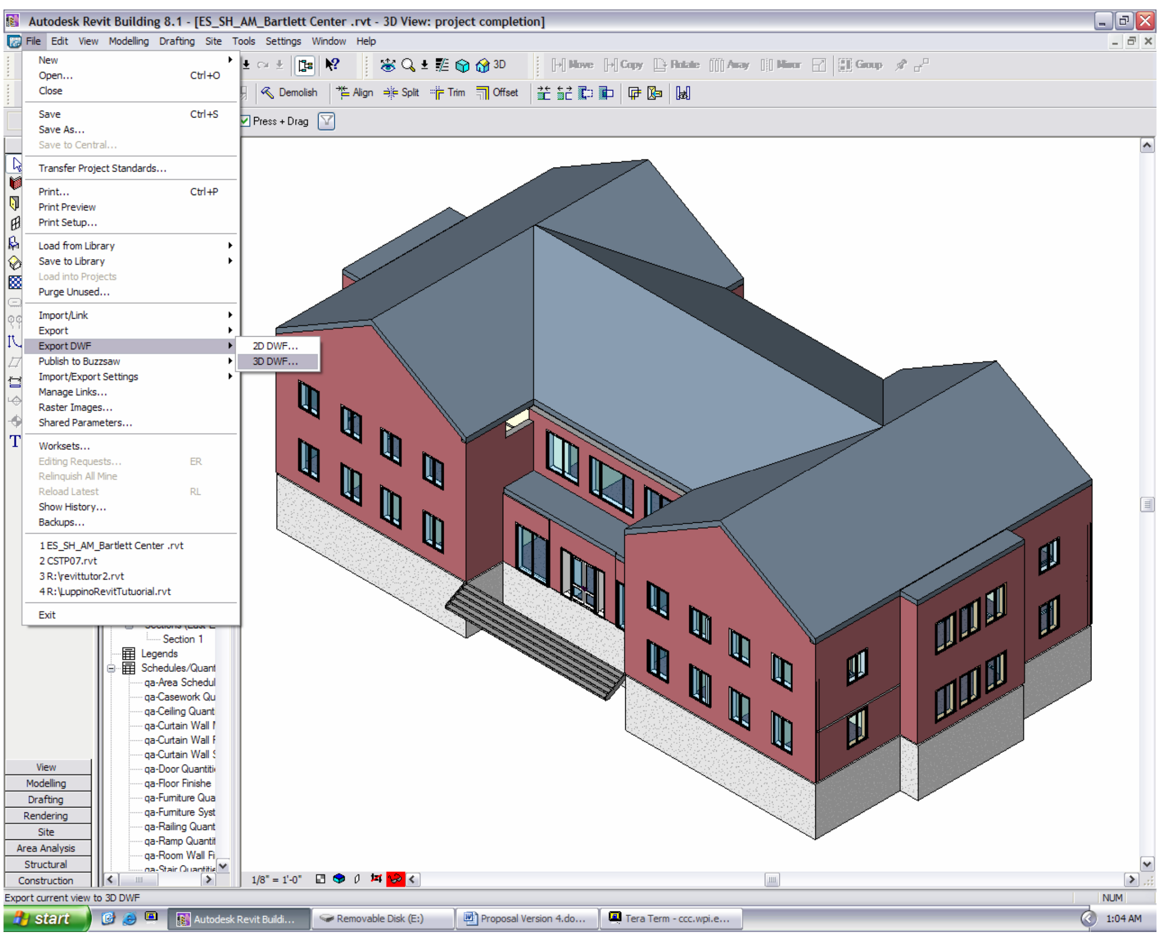

Figure 12: Autodesk Revit Building Bartlett Center

Utilizing DWF files and the DWF viewer was another important aspect of the system mock-up because of the concern of usability. Autodesk Revit is arguably not a difficult program to learn or use, but it is not a widely used program, and is also expensive. Other programs frequently used at WPI such as Autodesk AutoCAD and Pro Engineer are not available on all computers. The installation of these programs onto a machine requires WPI Network Administrator approval, which is somewhat difficult to obtain. In addition, even if Revit were made available on every computer, there might be difficulties with the user license. Generally, Autodesk provides a 30-day free trial, and then requires registration. If the software is not registered, Revit will automatically make itself available as a demo version, where changes made to a drawing cannot be saved, regardless of how much has been changed, even the most minimal change cannot be saved with the demo. Rather than cause WPI Plant Services to have to become concerned with this issue, it was proposed that the Autodesk DWF Viewer, which is free and downloadable from Autodesk's website, be implemented. In addition, it is relatively simple to use as well as easily obtainable, virtually presenting the same ease by which to obtain Adobe Acrobat PDF, which is widely used software for posting and reading documents.

The Autodesk DWF Viewer is a versatile tool serving many purposes. Once the Revit model is exported and made into a DWF file, the DWF Viewer is the program needed to access the file. (See Figure 13)

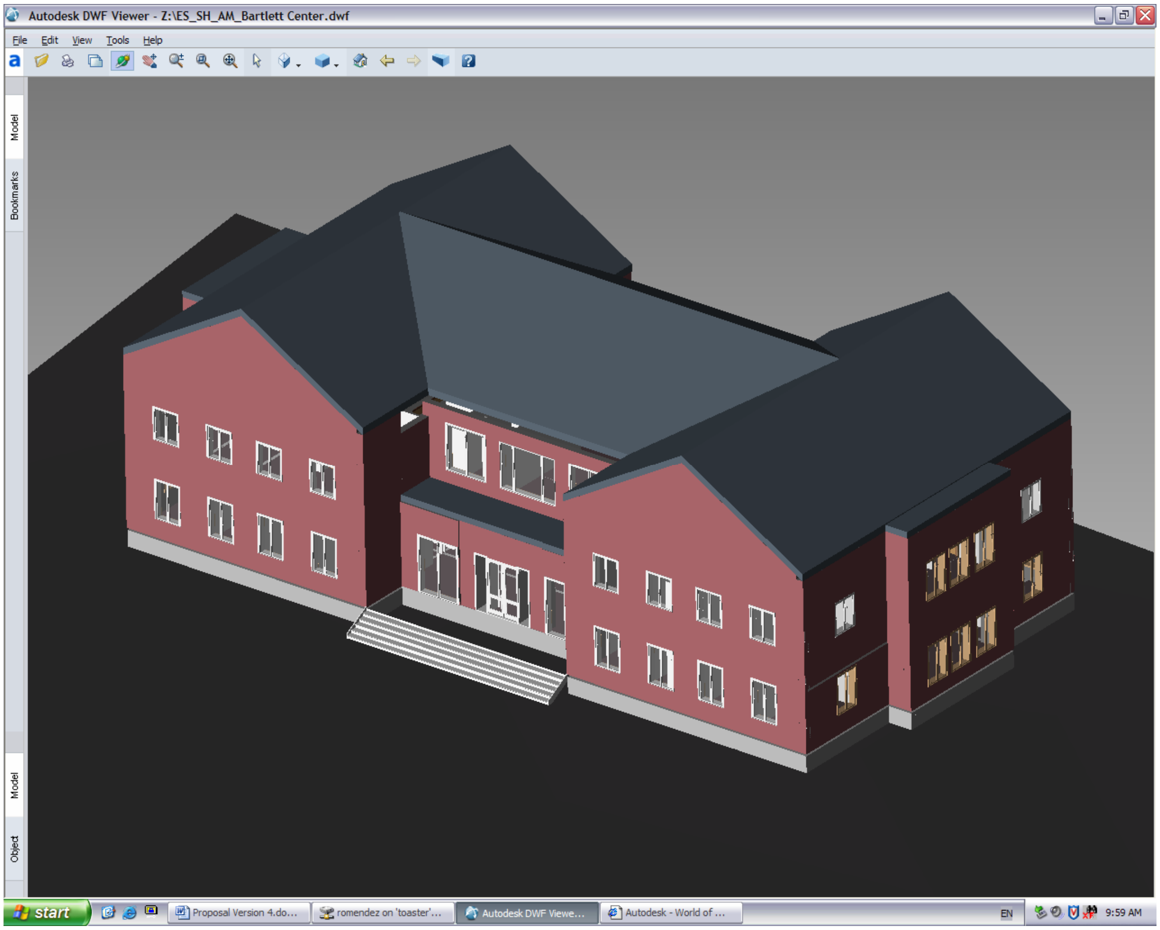

Figure 13: Autodesk DWF Viewer Bartlett Center

The DWF file maintains data-rich design information built into CAD files and 3D models at a fraction of the size (Autodesk, 2006). The sharing of the drawing file and information is made possible through the distribution of published design files, and not the original file. The DWF Viewer gives anyone the ability to view the file content without requiring the software that created it. For instance, an AutoCAD drawing or Revit model can be viewed without requiring either software to be installed on the computer. Another benefit is that the DWF Viewer can potentially save on printing and shipping costs as the DWF file can even be sent to other project members via electronic mail. Despite the smaller file size, the drawings still maintain a high level of resolution. (See Figure 14)

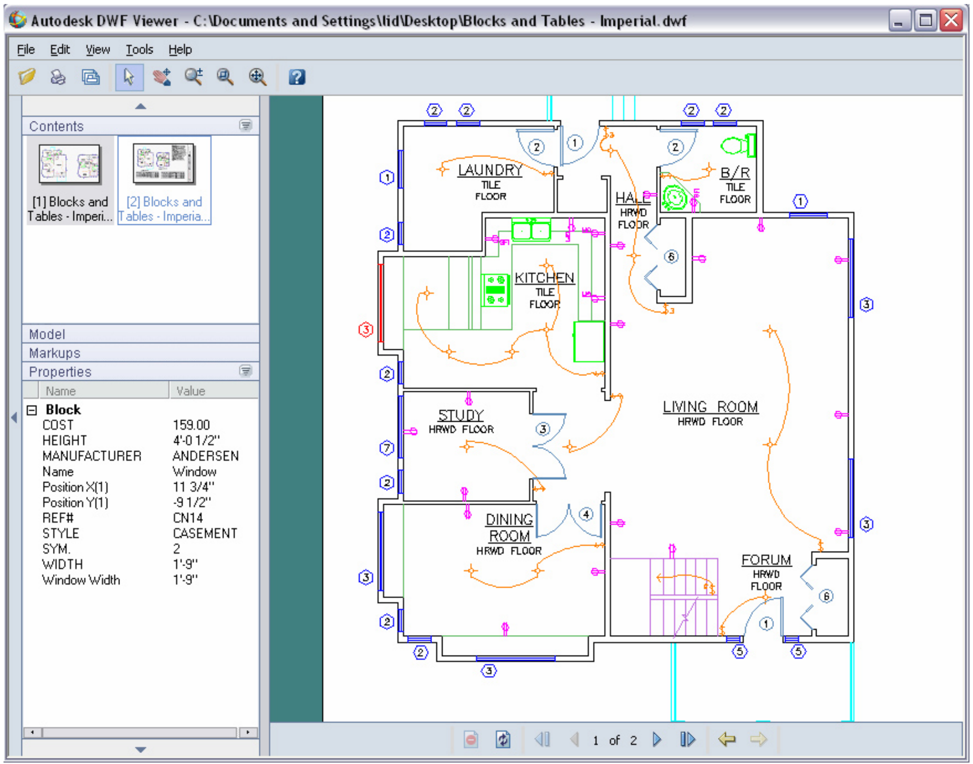

Figure 14: Autodesk DWF Viewer- CAD drawings
(Autodesk, 2006)

Three dimensional models that were generated in AutoCAD or Revit can still be viewed with the DWF Viewer's 3D features. The DWF Viewer can display 3D cross sections as well as 3D move and rotate, where individual parts can be pulled away and placed in their respective original positions (See Figures 15 and 16) This feature is available on the latest versions of the DWF Viewer.

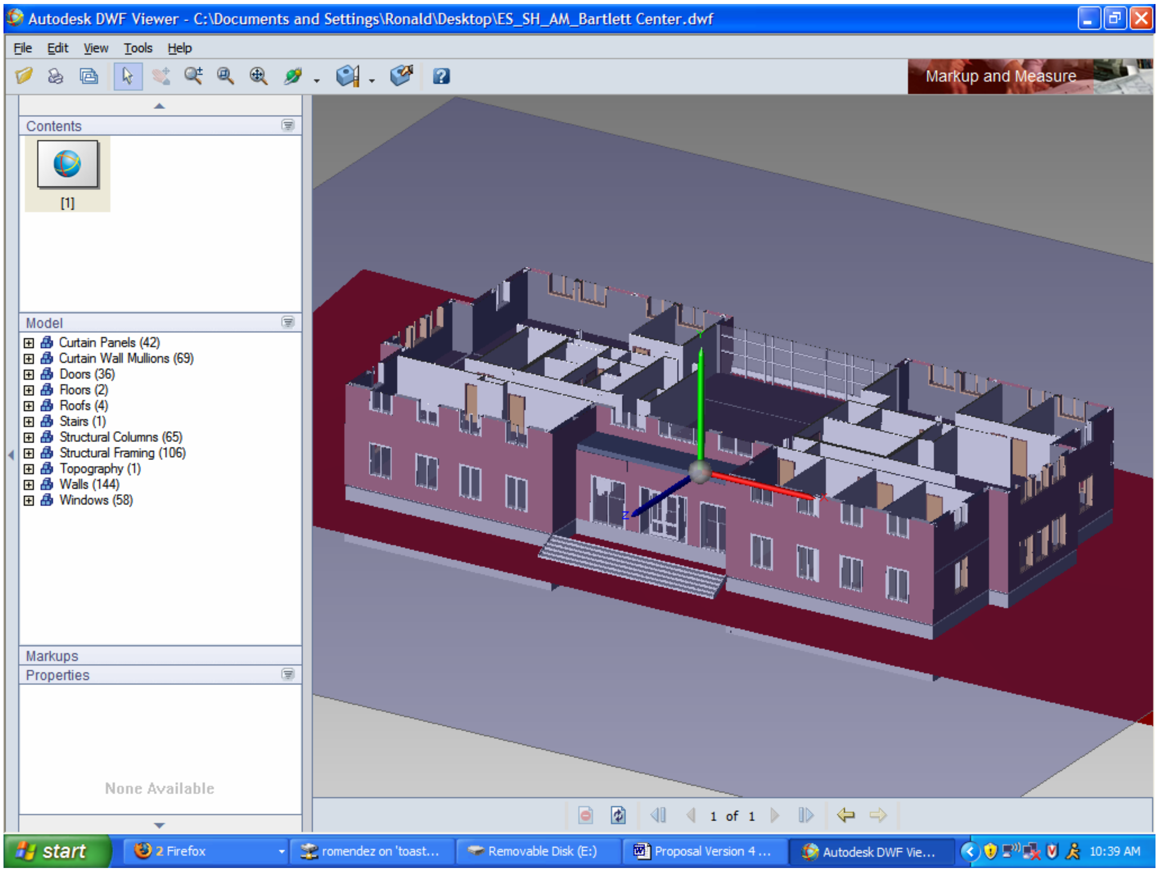

Figure 15: 3D Cross Section

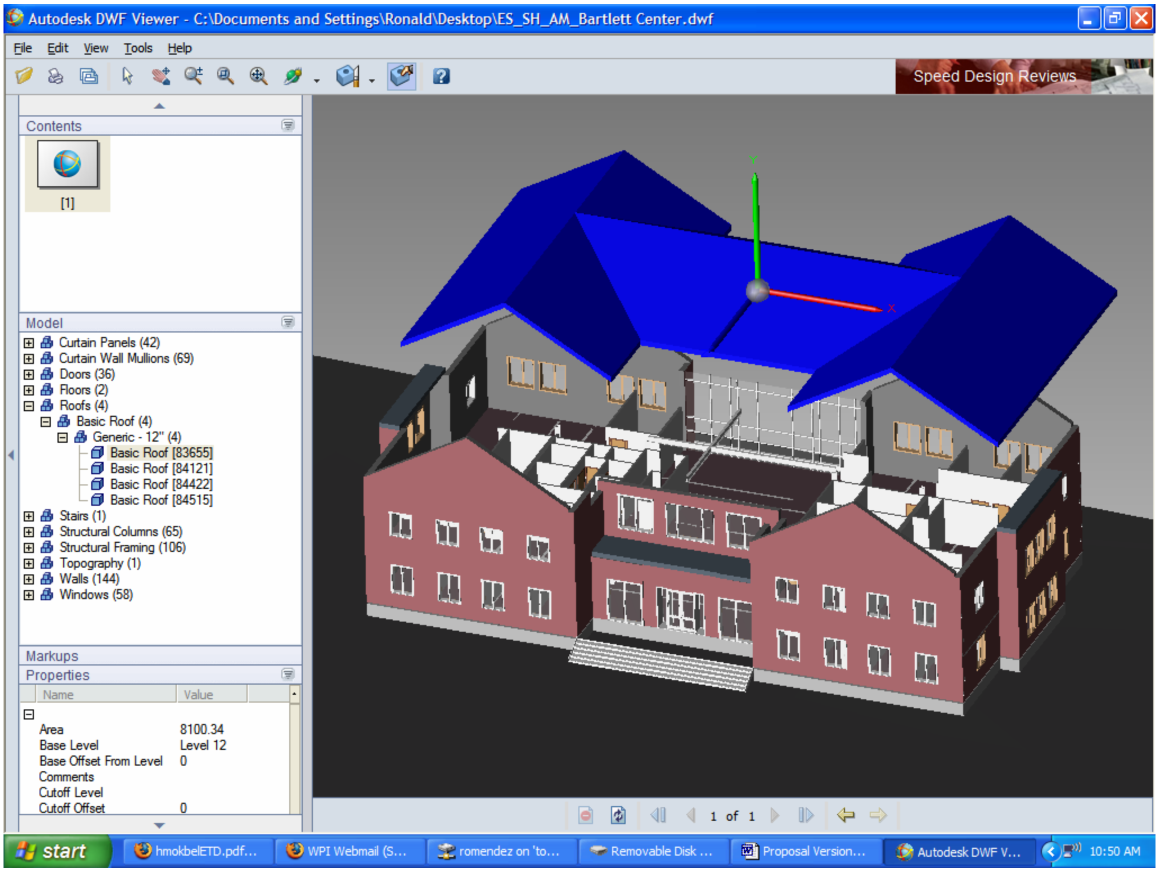

Figure 16: 3D Move and Rotate

The DWF viewer can be used in combination with Microsoft Office programs and Windows Explorer. Programs such as Excel, Word, and PowerPoint can be used by simply placing the DWF file into it. The Windows Explorer integration allows the preview, search, print, and email of DWF files. In addition, DWF files can be posted on a webpage in the same fashion that a Word or Adobe file can be posted. However, one area where the program is limited is combining the DWF file with Adobe Acrobat files. Perhaps this is an item that will be addressed in the near future.

Another added benefit of the Autodesk DWF Viewer is its cost. The DWF Viewer gives the user the ability to view Autodesk-produced drawings, regardless of whether it is in 2D or 3D. The viewer can also display information such as cost, code, and assembly.

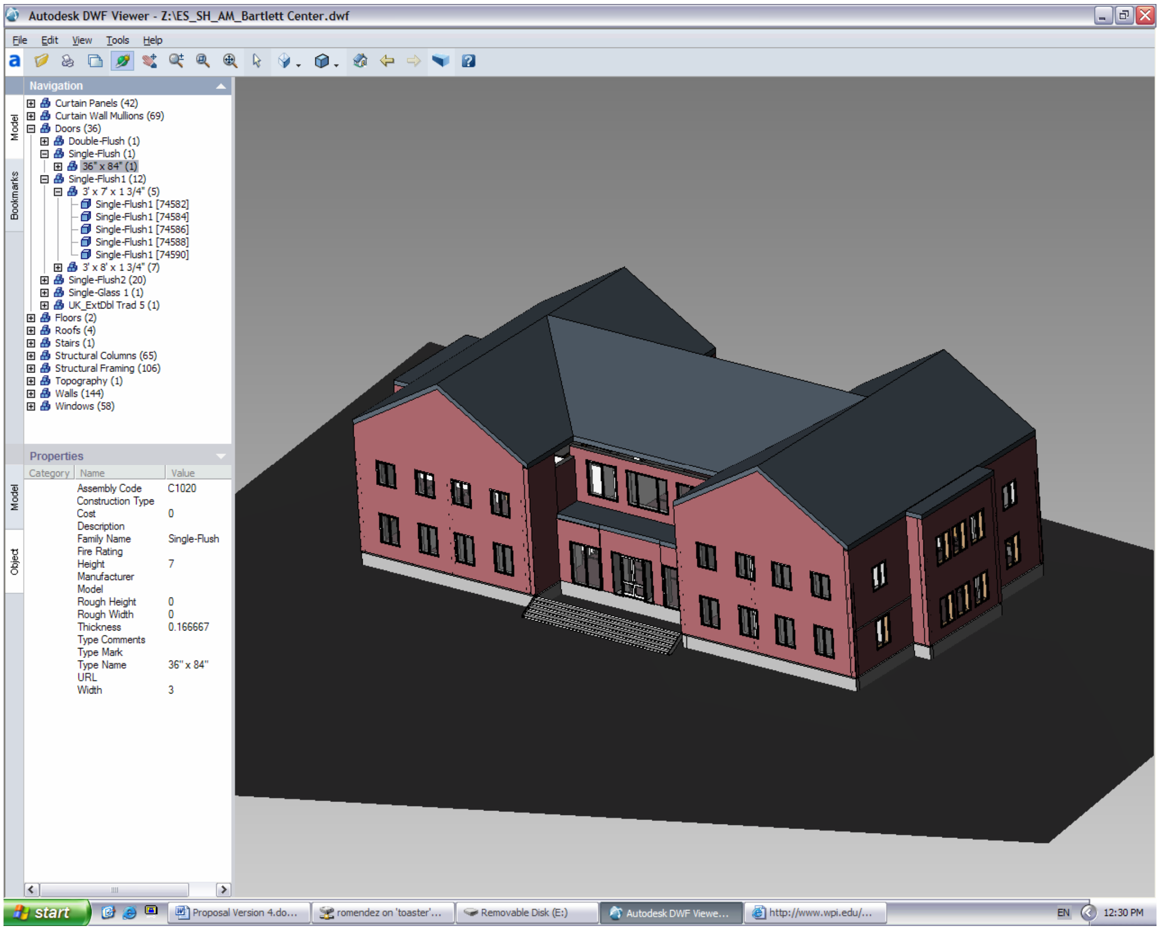

Figure 17: DWF Viewer with Properties Sidebar for General Group

The properties shown in the side bar differ depending on the component chosen. For instance Figure 17 shows cost, description, fire rating, manufacturer, and URL for specified door type. Those properties are no longer shown when a specific door under said category is individually selected as shown in Figure 18.

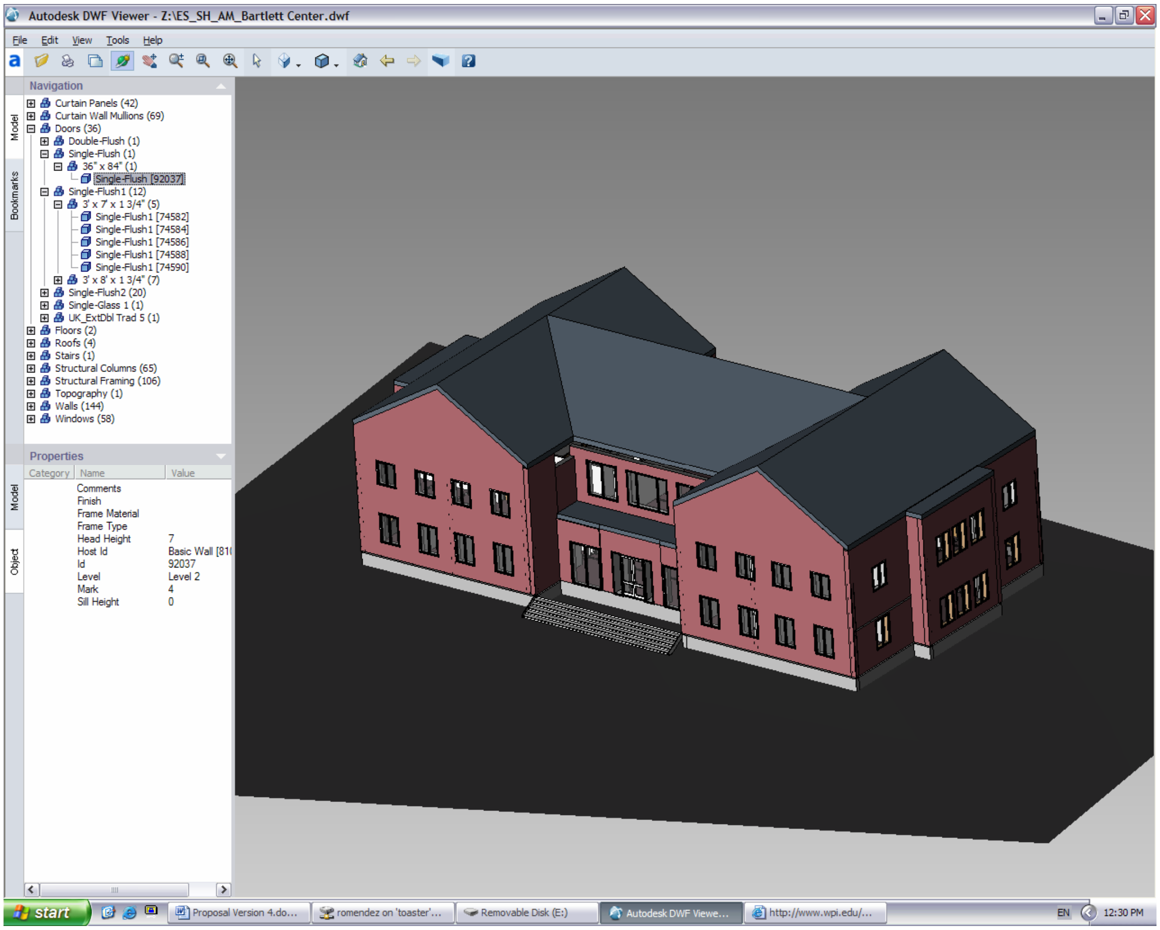

Figure 18: DWF Viewer with Properties Sidebar for Specific Component

Using the DWF viewer will not require a capital investment on behalf of Plant Services to post the desired building information. Furthermore, the DWF files are relatively small files, generally in units of kilobytes, compared to a Revit file which would be at least 1024 kilobytes (or 1 megabyte) of memory. For instance, the Revit model of the Bartlett Center is approximately 3.8 megabytes while the DWF file is around 130 kilobytes. However, using the DWF viewer will inherit certain limitations. The viewer will serve more as a visual model unless the desired information is prepared and recorded in the original Revit model. There are other programs that address facilities management, and provide of variety of services. Some services are space management, furniture and equipment management, and condition assessment. The concerns with these programs are arguably training and cost. An E-Buildings Interactive Qualifying Project revealed that a university uses a facilities management program that few know how to use (Halilaj and Mills, 2006). This is a result of limited training and exposure to the software. By no means is the program useless, it is quite extensive, but it still highlights the concern of user friendliness.

The Autodesk DWF viewer is a tool that streamlines communication among the project team, especially for those members that are unfamiliar with CAD. This by itself is very important as it was discovered that neither WPI Plant Services nor any of the other facilities departments of the surveyed universities used CAD to any degree. The reasons were that CAD was not considered important or necessary to how tasks were accomplished, and that many, if not all, of the department employees did not know how to use CAD, primarily because there was no need for it and they were not taught how to use it. With respect to the previously mentioned facilities management software, user friendliness is very much an issue. The idea is that programs like the DWF Viewer can be used to graphically display a building and its respective information to those who need it. In a sense, it would be similar to how the Internet is extensively used to locate a street address, and obtain driving directions to and from said address. A decade ago this was not common since the common reference was the road atlas. In a similar sense, the Internet can be used to make the building information accessible.

In addition to the creation of the DWF file, it was necessary to obtain information about specific building components, more specifically the manuals, instruction and installation sheets, and warranties that were submitted by the various contractors and trades. The information included components such as doors, windows, plumbing fixtures, lights, elevator, HVAC and other selected mechanical pieces. The information was obtained from the project manager with permission of Plant Services. The various manuals and guides were then scanned into PDF format. For items such as the elevators, the entire booklet was scanned while selected chapters of the HVAC section were chosen. Once scanned, the PDF files were posted onto a prototype webpage. Also, the DWF file of the Bartlett Center was posted on the following URL address http://users.wpi.edu/~romendez/mi%20webpage%202.0/index.html.

Implementing the DWF Viewer did present some limitations in comparison to using Revit. Revit can produce schedules of the various building components, as shown in the following table.

Schedules produced by Revit		
Areas (Gross Building)	Furniture Systems	Rooms
Areas (Rentable)	Gutters	Site
Casework	Lighting Fixtures	Slab Edges
Ceiling	Mass	Specialty Equipment
Curtain Panels	Mechanical Equipment	Stairs
Curtain Systems	Parking	Structural Columns
Curtain Wall Mullions	Planting	Structural Connections
Doors	Plumbing Fixtures	Structural Foundations
Electrical Equipment	Property Line Segments	Structural Framing
Electrical Fixtures	Property Lines	Structural Rebar
Fascias	Railings	Topography
Floors	Ramps	Walls
Furniture	Roofs	Windows

Figure 19: Schedules produced by Revit

The DWF viewer does not have the ability to present tabular schedules in the same manner that Revit can. The viewer does give an accurate count of building components, for instance, doors, yet this is done in the sidebar found in the viewer. In the process of exporting a Revit model to the DWF viewer, some schedules are lost. It was deemed necessary to use a Revit model of a research center, which was provided by Autodesk, to explore the production of DWF files. The model was used also because of the extensive work that had been accomplished on the file, substantially more than on the Bartlett Center. Schedules and quantities found in the Revit file that were not found in the DWF files were gross building area, room schedule, furniture system, parking quantities, planting quantities, electrical equipment quantities, electrical fixture, structural framing information, and mechanical equipment. Given the limitation of the DWF Viewer, it was necessary to export the schedules found in Revit into Excel webpage files to be posted on the webpage.

A website was desired for primarily for two reasons. The first one was that the Internet is a widely used medium by which to post and share information. Arguably, most, if not all, tradesmen of the Plant Services can use the Internet. Or at the very least, an individual can be taught how to explore the Interest in a relatively short amount of time. The second reason was based off of the E-Buildings IQP effort of Andrew Mills (WPI '06) and Sibora Halilaj (WPI '07). The IQP focused on providing building management information for the use of the Plant Services, specifically examining life safety and building code compliance. The information was to make available through a website which ultimately intends to enable different parties interested in a building to obtain specific information most relevant to them. The parties taken into consideration were the fire department, insurance, building inspectors, and Plant Services (See Figure 21).

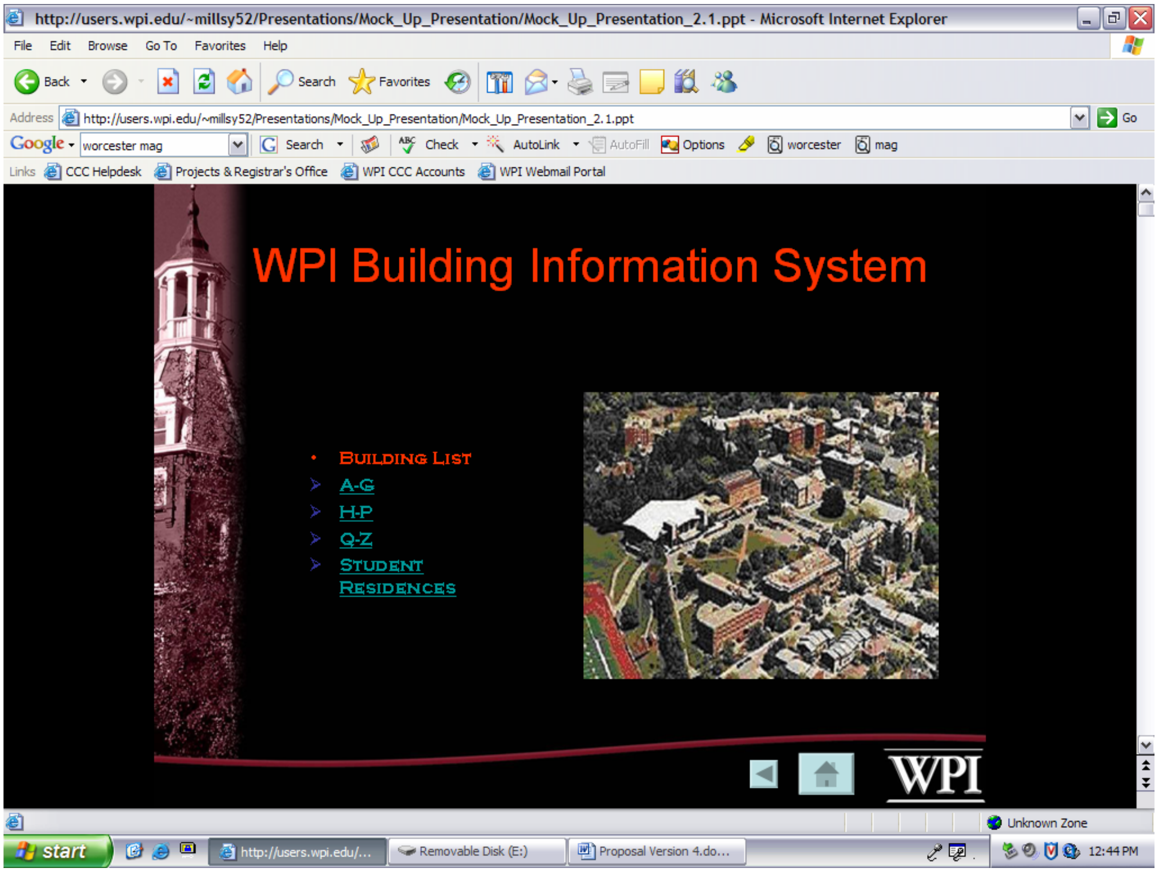

Figure 20: IQP System Mockup

The section for the fire department has information that is most relevant to them. Such information is the fire lane, compressed gas storage, and the heating plant. For the insurance company, the list would differ because of their involved interest, while Plant Services would be most interested in items such as the backflow preventer and emergency phones. The website displays the WPI campus map, but selection of a specific building is accomplished through the listing of the various buildings. Additional information contained about the building are items such as floor plans, fire extinguishers locations, egress paths, sprinklers, emergency lights, and shutoffs for electrical and fuel. The overall intent is making the relevant and desired building information accessible to the individual that needs it, whether it be Plant Services or the city of Worcester.

The Bartlett Center website was connected to the IQP mock-up system via a hyperlink. The added value is that not only can information about building safety be obtained, which is important to Plant Services, but access to building information and its components is also granted via the Internet. The connection of the Bartlett Center website and IQP website demonstrates that extensive information can be made available via the Internet. There also exists the possibility to link said websites with GIS (geographical information system). For instance, the website could function in collaboration LOUIS (Local On-Line Urban Information System), which is a web-based information system target towards municipalities and other authorities.

6.0 Conclusions & Recommendations for Future Work

6.1 Conclusions

The use of the BIM and information technology has the potential to change the face of the construction industry. The technology is available to begin filling in the communication gaps between the architects, engineers, builders, fabricators, suppliers, owners, and operators. After an initial loss in production, design time can be reduced by 40%, resulting in clearer information as well as more production discussion at a project meeting. Construction can be enhanced and shortened because of the visual ability to plan and coordinate. Operations and maintenance can be changed by having accurate and accessible information made available, thereby preventing tradesmen from having to wait for any needed information.

The limitations, however, are also substantial. One, the use of the BIM and information technology requires not only a change in the design and construction constituents, but also in the facilities management aspect. Of five institutions that were contacted, two were optimistic about the potential of information technology to improve the way information was managed and used. The remaining three believed information technology would be helpful, but its cost in terms of time, money, and personnel would outweigh the benefits. This situation was attributed to the low current use of technology in the departments, and the cultural reliance on paper. The reliance on paper was also influenced by the thought of not needing or wanting to have to learn how to use software in order to complete a maintenance task. Another reason was because of the reliance on C- and D-sized paper drawings. One party considered that it was difficult to fully grasp and comprehend the complete image of a plan on a computer screen. This is understandable, but a question that arises is about the need for such drawings at all times.

Perhaps large screen plasma screens can be used for this purpose. A cultural change on behalf of the facilities management personnel to use information technology as part of their procedure and routine is needed.

Accessibility was another topic that had to be addressed. Software such as Autodesk Revit can generate schedules in the file, yet these programs are not easily obtainable. Revit does require an investment, and to some parties, it may not be worth it, perhaps more so for facilities managers. This is based on the slow acceptance rate of the program by architects and engineers who would use the program more extensively. In departments where even CAD is not used, Revit would arguably pose as a huge jump and transition. Additionally, Revit requires hardware that is capable of supporting it, and some parties may not have that. During the data gathering process, one institution expressed that institutions like WPI are technologically capable of supporting such software, but others may not be.

Arguably, Revit will become widely used among facilities managers and operators in the same manner that Word and Excel are commonly used program. Indeed, CAD is not widely or extensively used, yet the BIM presents a much more complete perspective of a building as opposed to the slices of the building displayed with CAD. Initially, it was thought that the BIM would immediately be accepted by all project parties, most of all, the owners, managers, and operators because of information that could be presented and made accessible. Yet, this was not the case when it was found through the literature review and dialogue that there is some resistance towards applying new technology. The research revealed that some supported using the BIM and others did not. It seems that there needs to be a gradual approach to how the BIM is implemented.

In this case, it was found necessary to use the DWF Viewer not simply because it was free and easily obtainable, but also because of its ease of use, compatibility with software such as Microsoft Office, and its ability to present and share information.

The website was then considered important to present the BIM and its various components. The intent was to make operations and maintenance and information management more effective. It was considered that the Internet would be an excellent medium by which to do it based on the widespread use of the Internet. However, one concern is the format of the webpage. Initially, the website was made using frames, but then the inconsistency presented by frames was discovered, and drop down menus were used instead. Another thought is the level of complexity that increases with the size of a building. For instance, the Worcester Trial Courthouse (also being constructed by Gilbane) would require much more records to be stored and displayed on a website.

Another area of concern that arose during discussion was that of access and safety regarding who would be able to access the building information, since items such as sprinklers and fire alarms were posted in addition to a 3D model that displayed entrances/exits, rooms, and even structural information. With the release of Revit Systems, the DWF file could show the location of ducts, plumbing, and electrical pieces. In this day and age where building safety and security have become important issues, even matters like access to vital information need to be considered. The building webpage would not be expected to be posted on an open website, but rather be protected and accessed with a password.

The BIM in facilities management requires a gradual approach. In the meantime, the Internet must be used, and should continued being used, in conjunction with software such as the Autodesk DWF Viewer. The Revit and Viewer software both present limitations. Ideally, a building component should be highlighted and an option presented to access any relevant information. The technology is not altogether at that point, but it should be soon. Despite some resistance in using information technology, facilities management can benefit from the increased accessibility and availability of building information through the use of the BIM, it seems to be a matter of time.

6.2 Recommendations for Future Work

The use of the BIM in the design and construction phases in relatively new, yet even more so in the operations and maintenance stage of a building. This fact gives way to numerous potential areas to be studied and determined. One most intriguing area that was not within the scope of this research was that of the mechanical, electrical, and plumbing aspect of a building. Further research could be conducted with the current release of Autodesk Revit Systems. In addition to Autodesk Revit Building and Autodesk Revit Structure, the BIM is arguably closer to becoming a complete model. In doing so, topics such as life cycle and cost could be investigated. Another area of potential research is that of the ability to use Autodesk Revit or other BIM capable software in conjunction with facilities management software such as Bacnet or SchoolDude. Perhaps in addition to this or as another independent investigation is the ability to use information technology in the evaluation and tracking of changes in a building during its use. Further work could be in the building permitting and inspection process in regards to document preparation for the initial and annual inspection requirement. Another venue would be for municipal building departments to use the BIM as a reference, somewhat in the same intent as Sanborne maps were once used.

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Appendix A- J. Miller Interview

Interview: J. Miller

What information about the building components is provided from the designer or constructor? Lately, it's been books/manuals that we received from the constructor. The Campus Center, for example, has a multitude of books, varying from general conditions to HVAC to warranties.

What do you think of the information that was provided?
The books were greater than expected. In recent years, constructors have provided more information in forms of books than in the past. Really it's because the amount of information provided has greatly increased. The Bartlett Center would most likely have the same amount of books made as the Campus Center despite the difference in size.

What are the areas of a building that are most commonly addressed?
Heating (HVAC) and electrical systems.

What are the current practices for addressing these two areas?
Generally, Fran Carranzi (Lead Electrician) and Dave Lindberg (HVAC) will come into the office and review the manuals before working on whatever they need to work on. They take time to understand the information provided so they don't blindly go into the work they need to get done.

Are these books usually reviewed?
Not really, just when necessary. The information is there and readily accessible, it is just a matter of setting time aside and looking for it.

What impact would information technology have on the current management style?
The impact would be almost the same. It may be more trouble than it's worth. In this department, AutoCAD is non-existent. Mainly due because many have never really had the need for it or have they ever been taught or trained to use it.

Is there any specific criterion that is expected in the Bartlett Center?
It's the use of common building products, such that the components installed in the buildings of the campus are as much similar as possible. For example, lighting fixtures is one area. Some companies that provided a certain fixture may go bankrupt and when it is necessary to replace a fixture, there is great difficulty.

Appendix B- C. Salter Interview

Interview: C. Salter

What is the current method of operations and maintenance?
On campus, we have the Campuswide Energy System, where we can already store information about what's in a building. It has an information manual, links to the manufacturer's website (that is a current trend), it can control equipment, and allows one to see the operation so as to better quantify and understand the process. Others might call it the Energy Management System, or Backnet.

What information about the building components is provided from the designer or constructor? Generally, the copies of the original construction drawings, some level of that would be in CAD form. It's the basic floor plans. It depends on the work that was done. The Power House, for example, I got everything I wanted because I worked with the contractor and the CM from the very beginning, hence things that were of concern to me could be addressed, and it saved time and integration. The specific criteria were told to the designers. Otherwise there is the concern of having to coordinate all the various systems, and then you have a mess of things when the parties involved don't understand each other.

What do you think of the information that was provided?
It's acceptable but it would be great to get as-builts for the subsystems, such as electrical, fire protection, mechanical, and the fire alarms. Something about fire system is looking at the peak load, smoke detectors, and air handlers. That would things easier, and we thought we could do that when we hired someone to upkeep the digital information. However, that was not the case because of the card swipe issues that have recently risen. One thing is that you have to manage these systems (exterior masonry, electrical distribution, HVAC, and any energy efficiency projects), or they will manage you. We can't expect vendors to be the brains because we will shortchange a part of the business.

How is the information provided?
Currently, there is a cultural shift, but it mainly it is a combination of the two (digital and paper). And the product information is available online or found on a CD.

How do you use it?
We are working on developing second layer items, such as life safety. An important is developing consistency to integrate all the drawings. Important issues are life safety and inspectional items.

Any issues with warranties?
Not really, most of them expire relatively quickly. (one year)

What impact would information technology such the BIM have on the current management style?

From what I can see, not much application would be in facilities maintenance. More benefit in design and construction. Perhaps in the life of the building, such as logistical restrictions and any renovations that might be made, as long as people can use it.

Any long as people can use it?
Well, the information has to be kept fresh, and a person is needed for that. Also, the system has to be user friendly. Also, the information would be great, but what I've seen time and again is an information overload, but you need people in place to manage it.

Any other items of concern?
Access is an afterthought with architects, it's frustrating but it comes with the landscape. Other influential things are how well things are designed and how well is it built. For example, a residence hall at UCONN-Storrs was able to address the housing need, but it was horrible. Another things are green buildings. It involved a lot of stuff, but what about the companies that provide it, it could all cost more than expected. Really, it's amazing how much stuff you have to go back and change.

How do you change poor architectural design?
You change the business. Include the use of the CM, GMP, and VE.

What are the areas of a building that you expect to be addressed in the Bartlett building?
Mainly mechanical, and some electrical. For something like electrical, it would be knowing where things are.

Any other tasks?
The custodial work and the trades. And plumbing.

Appendix C- N. Benner Interview

Interview with Neil Benner

1. What will Gilbane give to WPI according to the contractual requirements?
As-builts of the structure, utilities, MEP systems; O&M manuals, warranty information, and RFIs.

2. Is this standard for the industry or just for WPI?
It is pretty standard for the industry. Occasionally, some specialty items, or owner-training sessions. Also, after some time an issue that comes up is whether or not we gave the client (owner) information about the building. For instance, if they ask about something, we wonder sometimes if we ever gave it to them.

3. What additional item do you think should be given to the owner?
A copy of approved submittals. One question that we ask is if the client has enough space to store all the books (or information) that we give them. Personally, I think about what the owner should get all the time, such as miscellaneous information like emails or PDFs.

4. What kind of requirements are really inconvenient or a pain in the neck to produce?
Nothing really. It depends on the contractor. Sometimes videotaping a training session because of what it entails. Going back to the contractor, it's about the as-builts and that those are clear and legible, and Gilbane revises the as-built progress where we will ask for it to be resubmitted if we are not content with it. Also, the specifications generally set the tone of the work, so we go by that. There really is no one thing that stands out. Considering O&M, it's easy, but the tough part is getting them (manuals) early. Also, the projects change in the site and location.

5. How involved is the documentation process?
Documentation isn't really a headache. It's been more so about getting the information from the contractors in a timely manner. It has been that they wait until the last minute to provide what we want, but at least it's done since we retained a percentage of their pay.

6. What information could you give that you could have given the owner/client at the beginning of project, design and/or construction?
The O&M manuals as soon as possible. Also, RFIs and submittals, as they are generated.

7. If something goes wrong after building construction is complete, what does Gilbane do?
Well, there is a warranty for a year for anything that goes wrong. We (Gilbane) do a walk-through a year after the project has been completed just to check that things are in working order. Construction is about repeat business so we take care of our clients. If something does go wrong after the warranties have expired, that requires us having to go through our storage rooms to find the boxes of the specific project. We will always

address the problem no matter how old the building, but we may not always solve it since there is only so much that we can do.

8. What do you think of the BIM?
I think it would help, but one concern is the accuracy of information. That could be a challenge. Also the time to make the BIM with all the information could be extensive. It would be good if submittals and RFIs could also be linked to the BIM so people could know how a component has developed.

Appendix D- University A Interview

Interview: University A

What is the current method of storing information for operations and maintenance?
We obtain three sets of O&M manuals and as-builts from the constructor. One set we keep in the office (on a shelf), the second set is kept at the Preventative Manual shop where the lighting and elevator systems are looked at, and the last is at the electrical shops.

What information about the building components is provided from the designer or constructor? We get all of the job records. That is, we get the correspondence, meeting minutes, anything regarding payments, change orders, all emails from the start to finish of the project, O&M manuals, as-builts, and CAD drawings. The CAD drawings are generally not used in our department. For our most recently built building, it was a LEEDS building. Some training also came along with the manuals because of how elaborate the building was.

What do you think of the information that was provided?
It's fine, because we normally get what we want. We set the processs.

How is the information provided?
It provided in paper form, such as in binders, and in digital form, such as compact discs.

How do you use it?
We go through the information as needed, generally the trade shops look at it when they have to. We also use some of the information to develop our preventative maintenance program, which is also based off the training that was provided. Some things needs regular attention because of the environment and the level of use.

Any issues with warranties?
Not really, we use them as necessary, and that information is kept track of. We just work through it.

What impact would information technology such the BIM have on the current management style?
I think it would be great to have. It's just a matter of time, money, and personnel.

What are the areas of a building that you expect to be addressed in the Bartlett building?
Mainly mechanical, and some electrical. For something like electrical, it would be knowing where things are.

Appendix E- University B Interview

Interview: University B

What is the current method of storing information for operations and maintenance?
We store the as-builts and O&M manuals in the plan room. Usually it's three sets of information. One for the mechanical and electrical, another for the trade shops, and the plan room.

What information about the building components is provided from the designer or constructor? We receive the as-builts of the site and MEP, and the O&M manuals. The as-builts are in CAD form. The manuals are provided in binders, some being up to six inches thick. Also, training will be obtained if applicable.

What do you think of the information that was provided?
It's acceptable. It just takes some time to understand it, like a good day.

Anything else you would like?
An architectural as-built because it could be used in conjunction with the RFIs since those document what happens. Otherwise you need to meddle with it (the RFIs). The architectural as-built will require extra pay because it is not an industry standard for the designer to provide it.

How do you use it?
We get to information from time to time. Usually it is on paper, and not so much on computer.

Any issues with warranties?
Not really.

What impact would information technology such the BIM have on the current management style?
Not really any difference. I think it's a matter of when people go back to review the information in 10 or 15 years, the ability to use the media on which it was created. For example, consider how we don't use floppy discs anymore, and now it is the CD or the thumb drive. The program is not so much the concern but rather the storage of the information. I rely on paper much more. I also think that some of the older tradesmen will not want to have to learn how to use a software program to obtain information about something they need to work on. It seems it will be a hassle for them. It also depends on whether the architect is willing to use information technology. Overall, longevity is a concern. Or what a hundred years down the road? In any case, a paper backup will be needed. As far as the issue of space, currently, we have enough space, and when it fills up and we need more, well, that happens. It's part of how things are.

What are the areas of a building that you expect to be addressed in a building?
Mainly mechanical, and some electrical, particularly the HVAC of a building.

Appendix F- University C Interview

Interview: University C

What is the current method of storing information for operations and maintenance?
We store the information on shelves and bookcases in our department office. Some items such as the Standard Operating Procedures are stored as booklets online, but that is done by an outside company that we outsourced.

What information about the building components is provided from the designer or constructor? We receive the as-builts of the site and MEP, and the O&M manuals. In addition, we get the construction drawings and the contract. We usually get 2 sets of copies, and in some cases, we get four. It depends on the depth of the work completed and also the arrangement that the college has made with the constructor.

What do you think of the information that was provided?
The information is satisfactory.

How do you use it?
We use the information when we need it.

Any issues with warranties?
Not really.

What impact would information technology such the BIM have on the current management style?
I don't think it would have an impact. Information technology could be helpful, but it requires education. For examples, most mechanics don't want to be bothered with having to go online to obtain the necessary information. It all goes back to paper because they will most likely print out a copy of whatever it is that they need. Databases need to be updated and be compatible with what you are using. In addition, the computer department at this school might not be able to support it like the way your school is able to, we are not so technologically advanced or inclined.

What are the areas of a building that you expect to be addressed in a building?
Most electrical and mechanical. But using information technology might not help in our case because I believe it does not provide the whole picture in the same way that a C or D print copy does. It would be hard to see it, like a floor plan, on a computer screen. Paper shows how much is there and the relationship of what items are present in the drawing.

Appendix G- University D Interview

Interview: University D

What is the current method of storing information for operations and maintenance?
We store the information at the library and where the equipment is located. Currently, we are in the process of setting 5 different locations with drawings, O&M manuals, and warranty information.

What information about the building components is provided from the designer or constructor? We get the as-builts of the MEP and site; I am not concerned about the architectural or in-progress ones, just the final ones. For the MEP, we get anything related to life safety such as low voltage wiring, sprinkler diagram, and fire alarms. In addition, any subtrade and/or system. We get the O&M manuals of all the equipment like the diesel generators, rooftop unit ventilators, and also the attic stock cut sheet if the manual is not provided. The warranty information is another thing we get, from the building envelope in, for labor and every piece of equipment. We have to keep abreast of that information because for example, a broad chiller in a residence hall that we have, has a caveat sentence that only a certified technician can touch it for five years.

What do you think of the information that was provided?
We get what we ask for. We don't believe in just getting the keys from the builder, it's just too costly.

Anything else you would like to see?
I think that perhaps getting digital pictures can be added. Perhaps not from the project team, but it would be good to have in the library because it's easy and reliable.

How do you use it?
We give the information to our trades. One other thing we do is that the construction and design documents are given to the trades at the beginning of the project so they can also identify any problems or difficulties. As previously mentioned, we are working setting up different locations with the information. The O&M manuals are in paper form near the actual piece/equipment. Another thing is 3rd party commissioning, which helps to go through things and really check into the items and get the stuff involved. (Commissioning is a formal procedure to insure that a new building operates satisfactorily to the owner's requirements.)

Any issues with warranties?
See above.

What impact would information technology such the BIM have on the current management style?
I think it would be helpful because it can save space and it is accessible. The information can be used to additional copies of it. Really, having all the information in one location is

risky or in paper form. I am reminded of one case at a school where a building that had all of the manuals and drawings burned down. See, that information was lost forever. Information technology would also have to be used with paper documents. On a side note, it might useful for obtaining the temporary and permanent certificates of occupation. You should what the requirements are for those certificates.

What are the areas of a building that you expect to be addressed in a building?
A lot of it is life safety, where we develop and use preventative maintenance, elevators, doors and hardware (things that get a lot of wear and tear), painting, and plumbing. Electrical seems to be the least common.

Other thoughts about information technology?
Perhaps a bridge could be made between the work order system and the Revit model. Consider some items such as backflow preventers, which need to be inspected, and emergency lighting, where an annual test is done. Anything that will make property management faster and safer is good because people are not harmed and things are less costly. What about cost?

Appendix H- State Building Inspector Interview

Summary of interview with Joe McEvoy

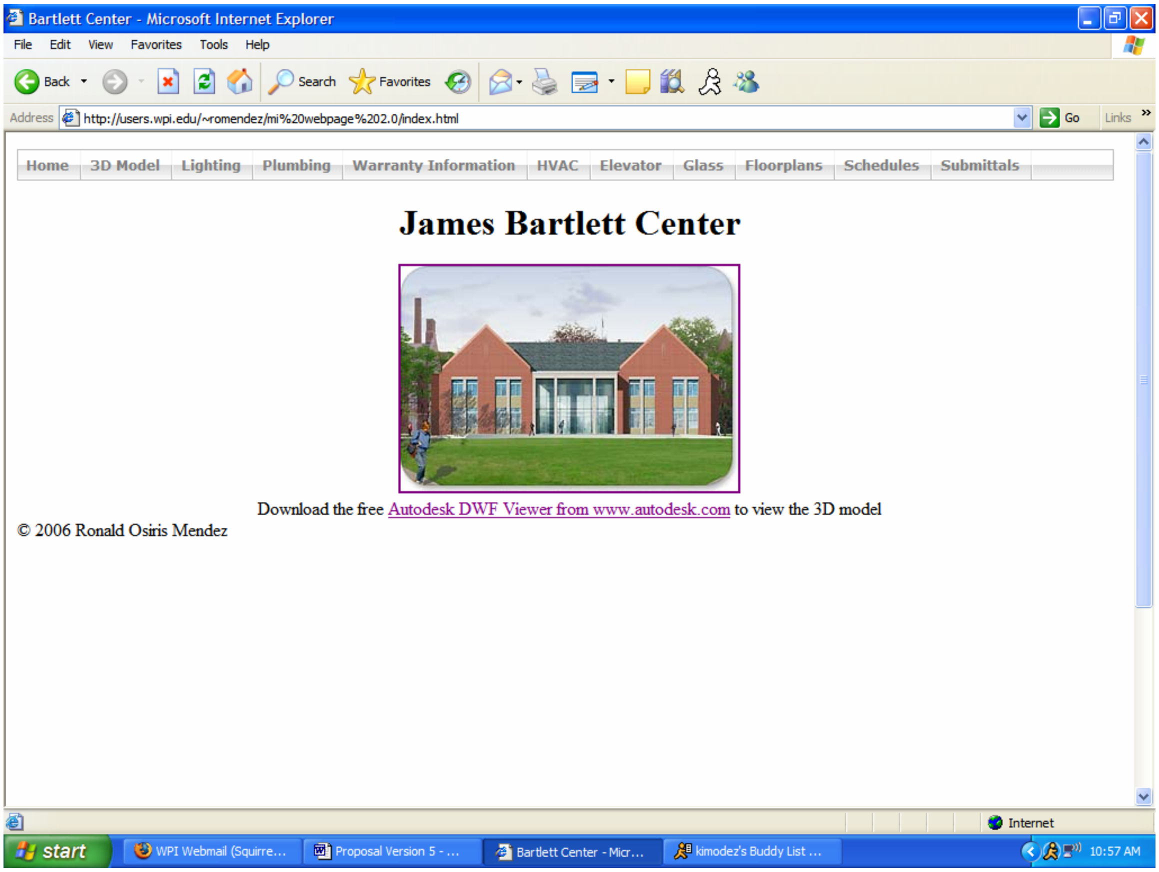
1. What is the process for a building to be granted a certificate of occupancy?
First of all, a temporary certificate of occupancy has to be granted. Obtaining that requires certain items such as the structural reports, and affidavits by the designers. I have a personal preference to how things are done. Some time ago, I developed a building data summary sheet to give a brief synopsis of all the items that are presented in the requirements. The data sheet also specifies what laws are relevant to a specific topic or subject. It serves somewhat as a cheat sheet since I could be asked, "Well, where does it say that?" and I can point to where in the code (Massachusetts Building Code) I am making my reference from. So really, the data sheet gives me a summary of all the relevant information of a building.

2. How is the summary sheet completed?
For example, on one project, the architect is completing the data sheet. As you see here, there are still some areas that need to be completed. Basically, the architect highlights the important aspects of the building. For example, once I generally get the building classification of a structure, I can pretty much infer the rest of the information about the building because the code specifies what conditions or characteristics are needed for a certain classification. In addition to the data sheet and the various reports, I also ask for the RFI log, the submittal log, and the proposed change order log. The reason is that when I look through these logs, I look for what has been a common or constant difficulty. That way, when I go through the building, I can keep an eye out for it. As for the construction types, the code has been evolving with it. Some of it has depended on the materials of construction and the fire rating of the materials.

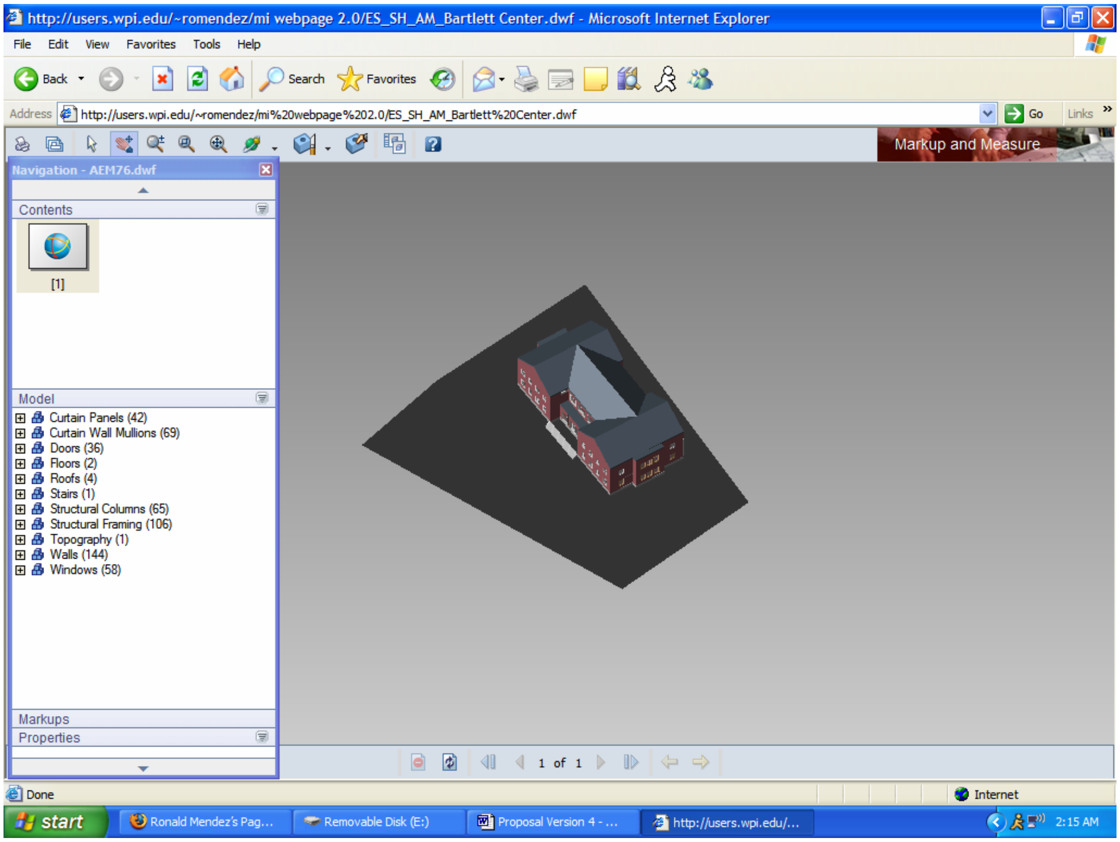
3. Any thoughts on the submittals given to the owner?
Well, as you see here, there is this list of items that I recommend that the owner obtain from the builder, such as the equipment operation manuals. They don't need to get it, but it would good to do so. (What about the warranties?) It's something they get, however, you should know that the warranty is not valid until the certificate of occupancy is authorized. There was this one case where a friend of mine at a college told me that a piece of equipment broke down and that it would be expensive to repair. He was concerned because the warranty have expired a couple of months earlier. So I asked him which building it was, and he told me. I remembered having worked on that particular building, and also never having granted a certificate. I told him not to worry about it because of that clause where if the certificate is not granted, then the warranty does not officially start. Thus, he was able to get the equipment fixed for free. Still, the computer is helpful. Most so the bigger the project, the more the computer helps.

4. Would items such as the BIM and Revit change how you do your work?
Probably not. It's still necessary to examine the building. The benefit is more so for the owner rather than for the inspector.

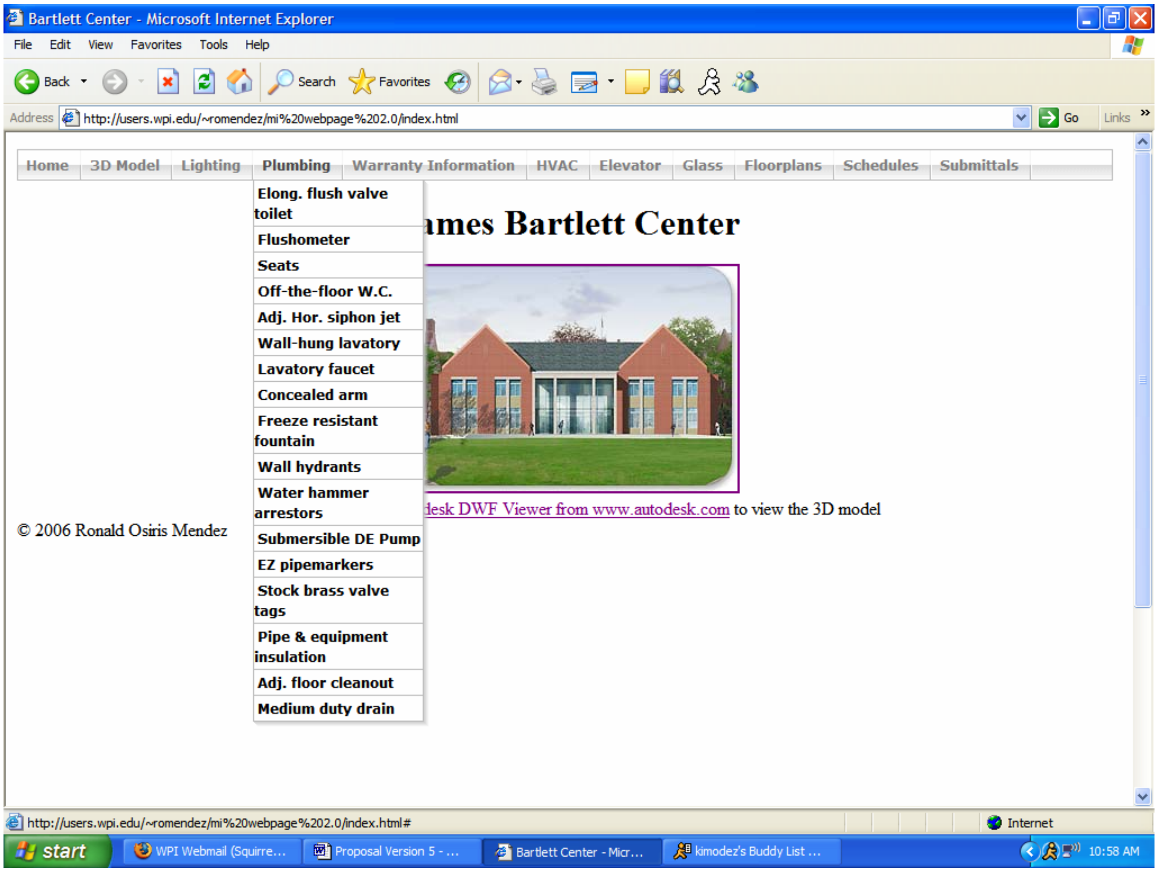
Appendix I- Website



Home page



Bartlett Center Model on webpage using Autodesk DWF Viewer



Sample image of drop-down menu used in website

Appendix J- Website Reactions

Website Reactions

Miller:
What should be added?
Nothing really. It seems comprehensive. Perhaps the record of submittals would be a nice thing to see on the website. The record of submittals would give information of the source, color, who furnished what, manufacturing, and the wholesaler of a particular item. For instance, I had a light break in the Campus Center, and I simply went through the records looking for who manufactured it and who supplied it, and the problem was resolved. This is not something you would get from the maintenance manuals, it's something apart from that.

Anything that should be removed?
No, it all looks good.

Is the organization acceptable?
Yes, everything relevant or of importance is there, plumbing, HVAC, etc.

Is it user friendly?
Yes, it is. It seems to make information accessible to anyone who needs it as well as readily available. Seems very useful in how it makes the information within easy reach via the Internet.

Benner:
What should be added?
Perhaps the final schedule. It may not have much use to facilities managers and tradesmen, but it could at least serve as a reference for anyone who may be interested in the information. For some of the mechanical equipment that was installed in the building, a maintenance software was included as part of the submittal. Ideally, it would be great to have this database (the website) be connected to the maintenance software. I can only imagine how helpful that would be.

What should be removed?
Nothing, it's great stuff. The content is good.

Is the organization acceptable?
Yes, it is. Straight forward information.

Is it user friendly?
For the most part, yes. There was one area that I thought about. It's the lighting tab. The names might be an issue since Plant Services might not call the lighting fixtures the same way we designated them as. (In the submittals, the fixtures were named LT 1 and so on. The website was initially set up with the lighting fixtures being labeled as LT 1, LT 2, etc. In response, the lighting submittal list or table of contents was included in the

website to address this.) Ideally, when you initially presented this to me, there was the idea to place the cursor a selected building component and a window would appear displaying information about the component. Maybe something like warranty information could be included in this. For this, a good way might be to include a key or a snapshot of the actual drawing. For example, the design drawing of the lighting on the first floor used these labels (LT 1, LT 2, etc.). A copy of this drawing might be helpful, thought it depends on the size of the building. The Bartlett Center is a small building, so it would not be difficult to identify and keep track of lighting fixtures. In a large building, this task could prove to be more difficult.

What about the model?
The model is great. The features of cross sections and moving pieces from the model are great.