DEVELOPING BUILDING INFORMATION MODELING (BIM) GUIDELINES FOR CAMPUS PLANNING AND FACILITIES MANAGEMENT AT WORCESTER POLYTECHNIC INSTITUTE (WPI)

By

Purvashri Vivek Padhye

A Thesis Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Master of Science in

Construction Project Management

January, 2017

APPROVED:

____
Prof. Guillermo Salazar, PhD, Advisor

____
Prof. Leonard Albano, PhD, Committee Member

____
Alfredo DiMauro, AIA, Committee Member

____
Prof. Tahar El-Korchi, PhD, Department Head

ABSTRACT

The development of Building Information Modelling (BIM) guidelines for campuses and universities has evolved on a case-by-case basis and there is no standard format in the development of these guides. There are however, common elements in these guidelines.

This study reviews the applications of Building Information Modeling (BIM) from the perspective of owners of higher education campus facilities and proposes a structured approach to develop documented guidelines to assist the owner's staff in the use of BIM, primarily with existing facilities. More specifically, this study proposes a set of guidelines to assist the Facilities Management department at Worcester Polytechnic Institute (WPI) in using BIM for their existing campus facilities.

Since 2005, WPI has been using some components of BIM in the design and construction of new facilities and has extended BIM uses to support facilities and space management in some of the existing buildings. Some positive experiences and benefits have been derived from these applications, but to date no formal and systematic approach has been established in documenting and organizing processes for the different BIM uses on campus.

The objective of this research project is to conduct an extensive review of documented approaches and guidelines for BIM uses developed by other universities and incorporate the different experiences with the use of BIM at WPI to create a set of formal guidelines exclusively for WPI for the efficient implementation of BIM in future design, construction, renovation, facility, and space management of a facility.

The research collected information from the WPI Facilities Management department through surveys and interviews, to better understand the current issues associated with facility management and space planning. A case study analysis that involved the use of 3D Building Information Models of several buildings on the WPI campus was performed to validate the possible use of the BIM in the efficient delivery of information for new and renovation projects as well as for its ability to benefit in the space planning process. Existing documented guidelines developed by five other universities that have pioneered the development of their guides were also reviewed to determine common elements in their BIM-based practices and to incorporate these when applicable into the BIM guide for WPI in such a way that will effectively contribute to the BIM adoption and standardization of procedures reflecting the unique characteristics of this institution.

This study identifies the benefits of utilizing BIM and standardization through the BIM guide primarily for existing construction and facilities management. The attempt to identify commonalities and standard pieces to develop a BIM guide for WPI will help improve overall operational efficiency and productivity of the organization. This provides a unique opportunity to be engaged in the process of standardization, using existing content as a reference to achieve harmonization of concepts, terms, definitions and the overall structure or framework that the documented guide is delivered within.

The outcome is a WPI-BIM guide which will help assist facility owners in developing an overall BIM strategy that supports the organization's core goals, develops the necessary contract conditions, and generates implementation plans to successfully execute BIM within the organization.

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to all those who encouraged me and helped me complete this thesis.

A special gratitude to my supervisor, Professor Guillermo Salazar whose guidance, contribution and encouragement helped me to coordinate and successfully complete this thesis.

I would also like to acknowledge with much appreciation the crucial role of Liz Tomaszewski, for her stimulating support and suggestions which helped to form the basis for this research.

I want to thank everyone at the Facilities Department for their valuable inputs and time to help formulate the research, especially Alfredo DiMauro, Jim Bedard, Bill Spratt, Roger Griffin, Theresa Mailloux and Nick Palumbo.

A big thank you, to Hannah Poirier for coordinating and organizing meetings and presentations with the Facilities Management department and Cynthia Bergeron for helping with the administrative procedures within the Civil and Environmental Engineering Department.

I would also like to express my gratitude towards my parents, Leena and Vivek Padhye, and Karan Barabde for their constant support and encouragement towards the completion of this thesis.

TABLE OF CONTENTS

ii. Abstract
iii. Acknowledgements
v. Table of contents
ix. List of figures
x. List of tables

1 INTRODUCTION: ... 1
1.1 Background ... 2
1.2 Research Interest ... 5
1.3 Need for research ... 6
1.4 Research objectives ... 7
1.5 Structure of Report ... 8
2 LITERATURE REVIEW ... 9
2.1 The Facilities Management (FM) process ... 9
2.2 Importance of BIM ... 9
2.3 The value of BIM for FM ... 12
2.4 Advantages of BIM for Facility Management (FM) ... 13
2.4.1 Space Management ... 14
2.4.2 BIM data for Operation, Maintenance, and Retrofits ... 15
2.4.3 Populating the FM database from a Building Information Model ... 15
2.5 Record and As-built Building Information Model ... 18
2.6 BIM Execution Plan (BEP) ... 19
2.7 Building Information Model – FM Database links ... 20
2.8 Use of BIM data for maintenance and Retrofits ... 21
2.9 Need for a BIM guide ... 22
2.10 Objectives of the guide ... 23
3 METHODOLOGY ... 25
3.1 Conduct a case study on the Facilities Management process ... 25
3.1.1 Interviews ... 27
3.1.2 Research ... 27
3.1.3 Survey ... 27

3.1.4 Proposal 28
3.1.5 Priorities 28
3.1.6 Design 28
3.2 Conduct a case study of existing university BIM guides 28
3.3 Develop a proposal for a BIM guide exclusively for WPI 29
3.4 Validate the contributions of the proposed BIM guide 30
4 WPI FACILITIES MANAGEMENT PROCESS 31
4.1 The Facilities Management department 31
4.2 BIM uses for FM at WPI: Existing Facilities 33
4.2.1 Work done so far 34
4.2.2 Process of creating BIM for buildings at WPI 36
4.2.3 Different model parameters 40
4.2.4 Use of the model: 42
4.2.5 Maintenance of the model 43
4.3 BIM uses for FM at WPI: New facilities 43
4.3.1 Case Study 1: WPI Sports and Recreation Center 44
4.3.1.1 Project Organization 45
4.3.1.2 Architectural and Structural Design 46
4.3.1.3 Cost and Schedule 47
4.3.1.4 Facilities Management 47
4.3.2 Case study 2: WPI Foisie Innovation Studio (New ongoing project) 49
4.3.2.1 Background 50
4.3.2.2 Application of BIM 51
4.3.3 Conclusion 54
5. CASE STUDIES 57
5.1 Identify information for Comparative Analysis 58
5.2 Review guides for common data fields 59
5.3 Mapping a common Table of Contents 60
5.4 Case studies 60
5.4.1 Case 1: Indiana University (IU) 60
5.4.1.1 BIM Execution Plan 62
5.4.1.2 IU IPD (Integrated Project Delivery) Methodology Plan 62

5.4.1.3 IU BIM Proficiency Matrix 63
5.4.2 Case 2: Pennsylvania State University 64
5.4.3 Case 3: Massachusetts Institute of Technology (MIT) 67
5.4.3.1 Renovations and space change projects requirements 67
5.4.3.2 Capital project requirement 68
5.4.4 Case 4: Georgia Tech University 69
5.4.4.1 BIM Execution Plan (BEP) 70
5.4.4.2 Integrated Project Methodology Plan (IPP) 71
5.4.5 Case 5: University of Southern California (USC) 72
5.4.5.1 BIM Execution plan 73
5.5 Conclusion 73
6 WPI-BIM GUILDELINES DOCUMENT STRUCTURE, CONTENTS, AND VALIDATION 76
6.1 Research findings 76
6.2 Document Validation 85
6.2.1 Proof of concept 85
6.2.2 User Feedback 91
7 CONCLUSION AND FUTURE WORK 93
7.1 Benefits of the BIM Guide 93
7.2 Recommendations 94
Bibliography 100
Appendix A: Terminology 104
Appendix B: Interview Data 110
B.1 Questionnaire for Interviews 110
B.2 Interview Feedback 111
B.2.1 Participant 1: Bill Spratt 111
B.2.2 Participant 2: James Bedard 114
B.2.3 Participant 3: Liz Tomaszewski 117
B.2.4 Paticipant 4: Nick Palumbo 119
B.2.5 Participant 5: Roger Griffin 121
B.2.6 Participant 6: Theresa Mailloux 123
Appendix C: Worcester Polytechnic Institute BIM Guide 125

LIST OF FIGURES

Figure 1: Cycle of using BIM in Facilities Management......3
Figure 2: BIM Lifecycle Participants......11
Figure 3: Facilities data links with other systems......14
Figure 4: The Components of a BIM Use......18
Figure 5: Purposes of BIM Use......18
Figure 6: COBie process......21
Figure 7: Facilities Department Organization Chart......32
Figure 8: Sample view of Salisbury model......35
Figure 9: Migrating from CAD to Revit......36
Figure 10: Sample of the drawing sheet......39
Figure 11: FICM Space categorization......42
Figure 12: Completed WPI Sports and Recreation Center Background......45
Figure 13: External Organization Flowchart......46
Figure 14: Proposed WPI Foisie Innovation Studio......49
Figure 15: Grotesque on Alumni Gym......51
Figure 16: Map of United States showing case study locations......58
Figure 17: Indiana University BIM Guide......60
Figure 18: Pennsylvania State University BIM Guide......64
Figure 19: Massachusetts Institute of Technology BIM Guide......67
Figure 20: Georgia Tech BIM Guide......69
Figure 21: University of Southern California BIM Guide......72
Figure 22: University BIM guides comparison......74
Figure 23: University BIM guides comparison......75
Figure 24: BIM guide project concept......76
Figure 25: Proposed WPI BIM guide......77
Figure 26: Drawing sheet indicating plans with detailed dimensions......86
Figure 27: Drawing sheet indicating Floor Finishes......87
Figure 28: Drawing sheet indicating Ceiling Finishes......87
Figure 29: Drawing sheet indicating Architectural detailing......88
Figure 30: Drawing sheet indicating Space Use per FICM codes......88
Figure 31: Drawing sheet indicating Space Use (door tags)......89
Figure 32: Drawing sheet indicating Space Utilization and room capacities. (Room Space Utilization chart enlarged in Figure 33)......89
Figure 33: Room Space Utilization chart......90
Figure 34: Drawing sheet indicating MEP Utilities and locations......91

LIST OF TABLES

Table 1: BIM guide project concept 17
Table 2: Comparison of BIM Guides 64
Table 3: Interview data tabulation 92

1 INTRODUCTION:

The maintenance and operation of buildings is often the longest and most expensive stage in the project lifecycle; it accounts for about three times the construction cost (Fuller 2010). The availability of timely and accurate information is an important key element for the proper operation and maintenance of buildings. This key information is usually generated during the planning, design, and construction stages of the facility and is usually delivered in the form of printed or scanned documents when construction is completed (Goedert & Meadati, 2008). These documents contain the final set of building plans reflecting the current state of the facility, called as-built drawings; a detailed list of equipment with serial numbers, model, make, etc.; and warranties and guarantees of the systems installed in the facility.

Gathering, organizing, and entering this information into the Facilities' Computer Maintenance Management System (CMMS) for a typical building can be labor intensive and, to some extent, an error-prone process with no additional value for the management of the facility (Gallaher et al, 2004). Building Information Modeling (BIM) is a technology based collaborative approach that enables different stakeholder and parties involved through the different phases of the life-cycle of a facility to generate, manage and share information through a 3D digital model. BIM is used to develop high performing, well-coordinated designs that deliver desired project outcomes. It is used in new construction, substantial renovation, major maintenance and improvement, extension projects with a wide range of alternatives or significant financial impacts.

1.1 Background

Building Information Modeling (BIM) as defined in the National BIM standard-United States “is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward” (National BIM standard 2015)

A Building Information Model has great benefits for developing and maintaining lifecycle data for different facilities. It contains data that can be accessed and exported for various uses during the lifetime of the building for facilities management and operations. However, the owner does not necessarily benefit from the digital model developed during design and construction in the future operation and maintenance of the facility. Due to lack of standardization on how these digital models and information exchanges are conducted, design and construction integration of BIM doesn’t necessarily result into an integrated, lifecycle management process.

A well-planned BIM-based lifecycle management process can be developed and documented as a set of guidelines that, together with the appropriate selection of software tools, can guide architects and contractors to deliver an information-enriched data model that is beneficial to the client. When it comes to owners of several large facilities such as universities, a provision of detailed guidelines and deliverable requirements for the use and reference of their facilities management building teams, can assist them in a smooth and successful campus management. For construction projects undertaken, in which BIM is used, it is important to put together a BIM Execution

Plan (BEP) to review and implement all aspects of the process during the various phases of the project. A BIM Execution Plan is a comprehensive document that helps the project team identify and derive the benefits of BIM for a project through the different phases of construction. The cycle of using BIM in Facilities Management is illustrated in figure 1 below.

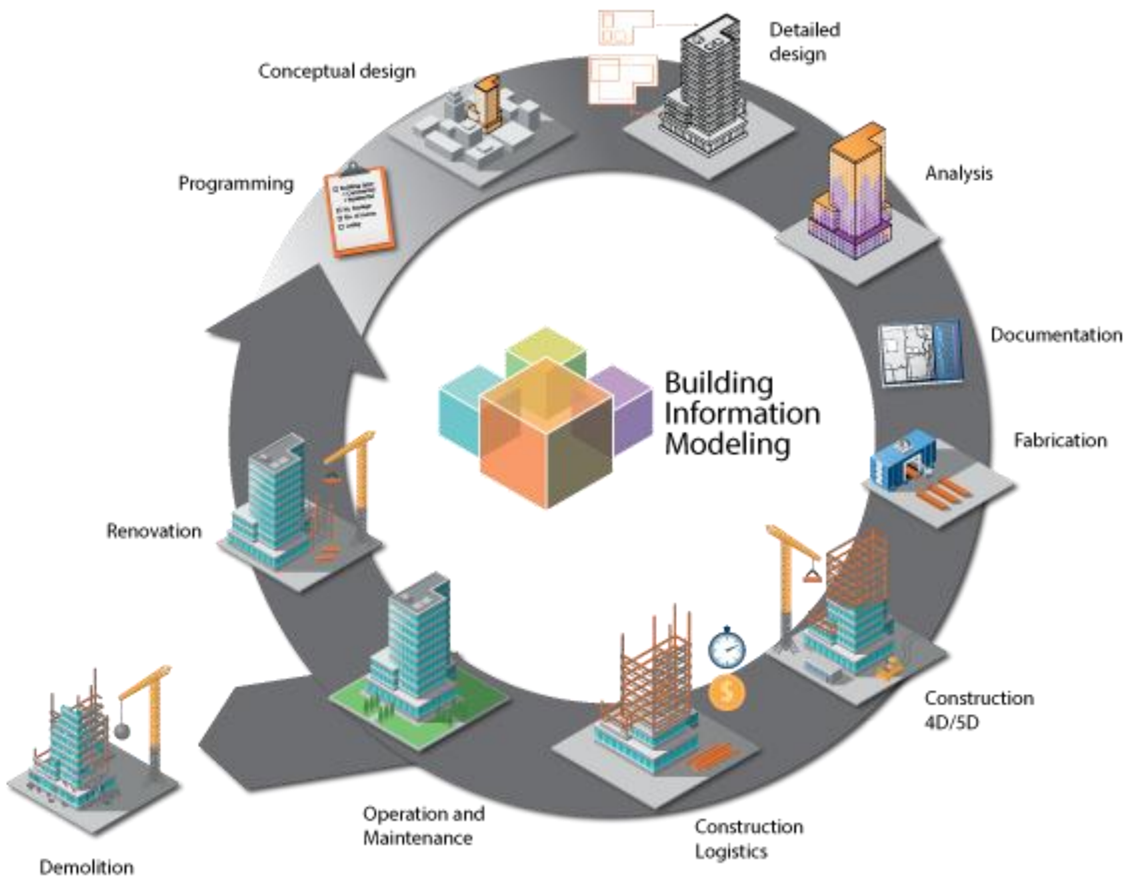


Figure 1: Cycle of using BIM in Facilities Management

[Source: http://cpmconsulting.rs/en/wp-content/uploads/2015/08/BIM.png]

The BEP is a formal document that defines how a project will be executed, monitored, and controlled with regards to BIM. A BEP is developed at the project initiation stage to provide a master data/information management plan and assists in assigning roles and responsibilities for model creation and data integration throughout the design and construction of the project. Unfortunately, the BEP does not include elements of the BIM-based life-cycle management and could vary from project to project. The availability of BIM guidelines could streamline and standardize this process making it evident that there is a need for the BIM guidelines.

The BIM guide can elaborate on the specifications of the BIM execution plan which includes detailed plans with standards, file names and different properties of BIM data which are specifically designed for the management of new and existing construction. In the United States, for building construction, Autodesk Revit software is typically used in BIM model authoring. The BIM model contains information that can be used to deliver this data. Construction Operations Building Information Exchange (COBie), which is a subset of Building Information Modelling, is used to help meet the facilities management (FM) goals. This helps improve the accuracy of the FM data increasing the efficiency of work order executions, in terms of speed, helps access data better and locating interventions (Graham Kelly et al, 2013).

Construction Operations Building Information Exchange (COBie) standard is related to managed asset information including space and equipment. It is an information exchange specification for the lifecycle data documentation and delivery of information needed by facility managers. It is a system that captures information during the design and construction of projects that can be used for facility management for operation and maintenance. This data can be viewed in design, construction, and maintenance software's as well as in excel spreadsheets making it easy to use on projects of all sizes.

The phases from design to construction typically take between 2-5 years to develop whereas the life of building lasts 20 years or much more. The lack of standardization on how this information exchange can be conducted and its integration with BIM does not yield the desired results, thus limiting the integration of design and construction information into facilities management.

A well-designed set of guidelines for the use of BIM plays a critical role for FM systems by providing 3D data that can streamline operations and maintenance over the long term. These guidelines ensure standardization of data that can be provided to the architect and/or contractor and then be incorporated into the Computerized Maintenance Management System (CMMS) software. The development of Building Information Modelling (BIM) guidelines for campuses and universities has evolved on a case by case basis and there is no standard format in the development of these guides. There are however, common elements in these guidelines.

1.2 Research Interest

This research analyzes the influence and importance of BIM for campus planning and facilities management and looks at universities that are already implementing it. The idea is to identify the best practices in the field and how successful they are in implementing them.

Since 2005, WPI has been using some components of BIM in the design and construction of new facilities and has extended BIM uses to support facilities and space management in some of its existing buildings. Some positive experiences and benefits have been derived from these initiatives, but to date no formal and systematic approach has been established in documenting and organizing processes for the different BIM uses on campus.

The author has been involved in the development of BIM models of some of the existing buildings on campus for the WPI Facilities Management Department and has identified the need to document the constant efforts conducted by the department for space management, for maintenance/operation/repair, for asset management, energy management and for the utilization of BIM in new construction and renovation on campus. This documentation could be better achieved with the help of a standard format/template like a BIM guide that would streamline the process moving forward with new and existing buildings.

1.3 Need for research

The development of Building Information Modeling (BIM) guidelines for campuses and universities has evolved on a case by case basis and there is no standard format in the development of these guides. Therefore, there is a need to tailor and adapt BIM guidelines and strategies to the context of WPI. For example, an incident occurred during a baseball match at Harrington auditorium in which a fire sprinkler broke unexpectedly causing water leakage. Unfortunately, it took the facilities department a while to locate the shut off valve causing inconvenience to everyone. The availability of BIM data could have helped the staff in locating these utilities and shut off valve to respond to the emergency faster. Most case studies on the successful implementation are the different universities across United States. The WPI campus and its operation has unique characteristics, thus, replicating strategies developed by other universities do not necessarily apply to WPI and yield the same results. Therefore, other experiences would have to be adopted specifically to fit the requirements at WPI. The introduction of the BIM guide for facilities management is an effort to standardize processes on campus and make data easily available for new and existing construction.

1.4 Research objectives

The objective of this research is to conduct an extensive review of documented approaches and guidelines for BIM uses developed by other universities and incorporate the different experiences with the use of BIM at WPI to create a set of formal guidelines exclusively for WPI for the efficient implementation of BIM in future design, construction, renovation, facility, and space management of a facility.

This project will seek to provide an evidence-based framework of solutions and suggest measures in the form of a BIM guide. The idea is to develop a BIM guide for WPI that will allow comprehensive facility information to be efficiently accessed. These guidelines will serve as a standard template/format that the end user can follow for new and existing construction through all phases of a facility's lifecycle.

The research conducted an extensive literature review and in-depth case studies of existing BIM guides of five (5) universities across the states. It looked at their current practices, handover process, operation, maintenance, and space management requirements as well as future requirements of the FM department generated using BIM technology.

More specifically, this research seeks to:

- Identify the value of BIM through the various stages of construction of a facility.
- Identify key information that should be integrated into the digital BIM model that will be relevant and beneficial to the FM department.
- Develop a BIM guide which will provide a defined approach for generating, integrating, and maintaining models and information that will be available and usable by the WPI FM department.

1.5 Structure of Report

The following chapters give a perspective on relevant data for advantages for BIM for campus management and some broad complimentary ideas which provide context to the relevant principles that are employed for this project. An in-depth literature review is conducted in Chapter 2. Chapter 3 looks at the methodology implemented for the research of the project. Chapter 4 discusses the existing BIM processes at WPI, what has been implemented on campus and existing and new projects utilizing BIM. Chapter 5 is a detailed study of the selected case studies and their relevance to WPI. Chapter 6 looks at the WPI BIM guide and the process of document validation. The final chapter, chapter 7 concludes the research and proposes a scope for future work.

There is no single correct solution to the development of the BIM guide. The evaluation of the case studies considers each place in its context. A technical validation through the pilot projects undertaken at WPI under the supervision of the facilities department will help analyze and design the guide; identify some questions and problem areas for delivering the guide.

2 LITERATURE REVIEW

This section reviews the current practices and processes involved with the facilities management and implementation of BIM for space planning, renovations, operations, and maintenance of a building.

2.1 The Facilities Management (FM) process

Facilities Management departments at any institution of higher learning play an important supportive role in the attainment of the intended long-term design objectives for the physical space. The Facilities Management process has its roots in the custodial role of buildings, concerning the operational issues of maintenance, cleaning, and tenant security (Best et al 2003). As buildings are becoming more complex, there is a need to introduce strategic short-term and long-term facility management strategies. This need is further amplified in the context of university campuses in which there are several buildings of diverse nature and use.

2.2 Importance of BIM

BIM is gaining importance in the design and construction processes for delivering facilities. BIM is not only important in the design and construction phases but it also helps in developing high quality 3D models containing information that can be used for supporting the management of the lifecycle of a facility. This information can provide significant benefits to the owner to support future renovations, operational procedures, space management of the facility and more.

With the help of BIM, owners are likely to see a high return on investment for a facility. It has helped improve project costs, project speed and facility quality. It also helps with better communication, lower project costs, avoiding rework, better project outcomes and higher building performance (Gilligan & Kuntz, 2007).

The Stanford University Center for Integrated Facilities Engineering (CIFE) reports the following benefits from the use of BIM. Based on 32 major projects using BIM, (Gilligan & Kuntz, 2007) the following benefits were indicated:

- Up to 40% elimination of unbudgeted change.
- Cost estimation accuracy within 3%.
- Up to 80% reduction in time taken to generate a cost estimate.
- A savings of up to 10% of the contract value through clash detections.
- Up to 7% reduction in project time.

Building Information Modeling, or BIM, as it is commonly referred to by project managers, architects, and other professionals who use it, is a process of creating and managing building data during the construction process (Lee et al, 2006). BIM is a framework in which a designer combines a three-dimensional model of a construction project with other information to provide more than just the visual representation of the physical building. The designer as well as the construction manager can then add in other dimensions to create a multidimensional model that not only encompasses the physical building itself, but a variety of other important factors in the project life cycle. Examples of higher dimension models are: a four-dimensional model that incorporates time into the project, or a five-dimensional model incorporating time and economic considerations.

These models can help to avoid construction issues involving scheduling, cost, or construction problems that may occur. The various BIM lifecycle participants are listed in figure 2 below.

Figure 2: BIM Lifecycle Participants

[Source: https://fmsystems.com/wp-content/uploads/2016/07/BIM-Lifecycle-Participants.png]

The common mistake people make with understanding what BIM is truly about, is to think that BIM is only a software program and it is not a broader approach based on information technology to promote collaboration. BIM combines the use of various software programs to create one, multidimensional model, rather than opening a software titled "BIM", and creating the entire model in one place. As it stands now, the three-dimensional digital image of the building could be constructed using one or more software packages and then further combined with other dimensions and information from other sources.

2.3 The value of BIM for FM

The integration of BIM for FM has a wide range of applications and benefits. For the research, it was crucial to determine where and how the implementation of BIM supports the FM process in campus planning and facilities management and adds value for the FM department representatives. The case studies conducted on the implementation of BIM for existing and new construction on campus helped clarify the need of a BIM guide for FM.

A significant amount of useful information is utilized and generated throughout the process of construction and post construction at closeout. Most contracts today require a list of documents at closeout which contain as-builts, equipment lists, warranties, product data sheets, operation, and maintenance schedule, etc. This information is particularly essential to support the management of the facilities by the owner/property manager/facilities department. The current process is generally done manually which tends to be often incomplete and inaccurate. The improvement of the handover/closeout process are one of the main drivers for using BIM in FM (Gu, Singh et al., 2008). BIM data and information collected during the process will add value to the building lifecycle and reduce the cost and time required to collect, build, and maintain FM systems. The data pertaining to spaces, areas, systems, finishes, etc. can all be built into a digital BIM format and accessed easily anytime in the future. This provides a fully populated asset data set which helps reduce time wasted in obtaining and populating asset information thus enabling to achieve optimum performance, reduce operating costs, and refine outcomes.

It is equally important to understand the challenges affecting BIM for FM applications. The main challenges of implementing BIM for FM is the lack of processes in place for updating the designed model with as built information (Gu and London, 2010). It is also sometimes unclear about who is responsible to load data, update and maintain the model. Facility managers are included in the building lifecycle in a limited way or at a later stage of facility handover. Thus, FM data is either lacking or inadequate. BIM is a relatively new concept to FM and adopting new processes and technologies is one of the key challenges faced by FM department. The FM industry is rigid in its approach unless the benefits of BIM for FM are clearly proven. Another challenge for the adoption of BIM is the shortage of BIM skills and interoperability between BIM technologies and current FM technologies (for e.g. Computer Aided Facility Management CAFM).

2.4 Advantages of BIM for Facility Management (FM)

Space is a very valuable and manageable asset, having intrinsic value for different purposes after a building is completed. Facilities managers have acknowledged the benefits of using the data available in the Building Information Model to assist with space management, operation & maintenance, asset management. These spaces can be managed in the model as the model can help populate the FM database saving labor, time, and money; assets can be effectively managed and as built information can later be used for retrofits.

- The model provides data required for FM that is useful for maintenance and repair of a facility.

- It helps to better visualize system components; ease of modification of information; secure availability of data for FM and the advantages of having one coordinated system for BIM.

This makes it increasingly important to link facilities data to all other databases like illustrated in Figure 3 below.

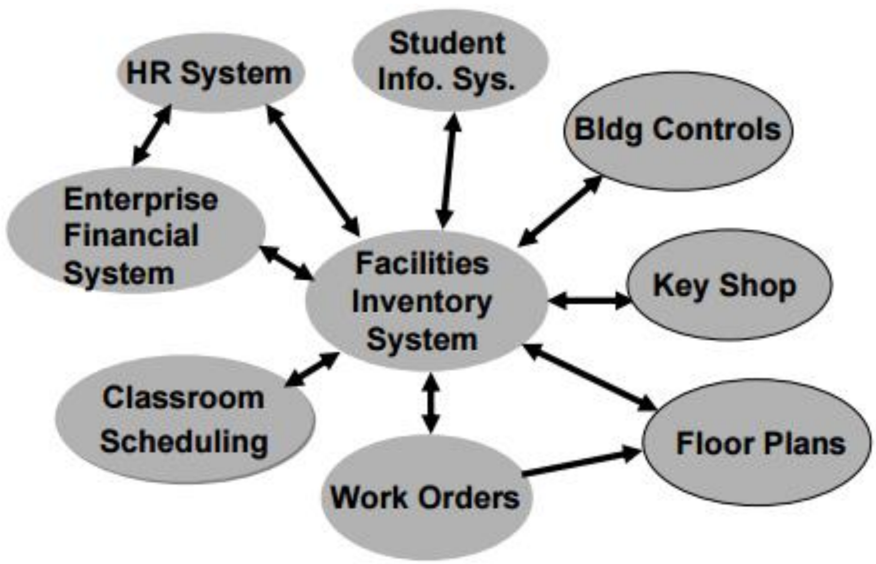


Figure 3: Facilities data links with other systems

[Source: Postsecondary Education Facilities Inventory and Classification Manual (FICM):2006 Edition]

2.4.1 Space Management

In space management, it is important to have detailed and precise knowledge of the type and amount of space available and associated items like capacity, type of use, type of materials, vacancy rates, equipment, furniture, lighting fixtures, etc. The size, location, use and contents are also significant. Spatial BIM helps focus on managing space as it is valuable and manageable asset. It has intrinsic value after the building is complete and is treated as a major tangible asset. The spaces in the building can be rented or assigned to people and are often the locator of items like equipment, furniture, voice and data lines, lighting fixtures, people, etc. This information can be quantified and made easily available with a BIM model and can be accessed through schedules or spreadsheets within the software and exported in a common file format for FM use. Different requirements can be tailored as per the needs of the owner into the BIM guidelines which can be utilized by FM through the lifecycle of the building for campus and space management.

2.4.2 BIM data for Operation, Maintenance, and Retrofits

Repairs and maintenance require a database of what exists and a timeline of when equipment needs to be fixed, upgraded, or replaced. This can be obtained from an accurate FM database. For example, an upgrade to the carpets in the building might entail replacing the old with new, characteristics of the carpet, links to manufacturer sites and specifications like thickness and materials can be in the BIM. Maintaining a BIM file with updates for facility management data are like maintaining to an actual facility. As the different components are repaired, replaced, removed, these changes will need to be reflected in the model. In fact, these updates can be easily done in the model prior to any work undertaken to calculate quantities, visualize how the new retrofits look in the existing building. The model gives the user the levy to work different permutations combinations before a final decision is made. Once these changes reflect in the BIM file, it can be used as an accurate as-built for future use.

2.4.3 Populating the FM database from a Building Information Model

Once a model that is fully populated with all the building components, facility managers and owners will have a much more powerful tool to manage a building. The model can become a complete repository of building information and data that formally had no shared, centralized collection point. The FM staff can extract this information to populate their CMMS systems.

The Facilities department does not operate in isolation. Their processes and data are always used in conjunction with academic, financial, human resource and student data.

The Facilities Management department classifies spaces consistent with those specified under categories in the Facilities Inventory and Classification Manual (FICM). The manual is a tool to help institutions/universities, and describes standard practices for initiating, conducting, reporting, and maintaining an institutional facilities inventory. Once completed, this facilities inventory will enable an institution to measure the ability of its space to meet its current programs, assess the current operation costs of its facilities (maintenance, utilities, cleaning, etc.), and then begin to plan for future space needs (FICM, 2006).

The categories encompass all types and uses of assignable and non-assignable areas found in campus buildings. A standard coding system is intended to provide meaningful and comparable summary data that assists all institutions to map comparable spaces to the same category. All assignable spaces are classified into 1 of the 10 major assignable use categories and all non-assignable space are classified into 1 of the 3 major non-assignable use categories listed in Table 1 below. This space use coding is intended to identify only the specific architectural use of an individual space; it does not help tracking other conditions or circumstances about a space.

Table 1: BIM guide project concept

[Source: FICM, 2006 Edition]

Classrooms (100 series)	General purpose classrooms, lecture halls, recitation rooms, seminar rooms, and other spaces used primarily for scheduled nonlaboratory instruction.
Laboratory Facilities (200 series)	Rooms or spaces characterized by special purpose equipment or a specific configuration that ties instructional or research activities to a particular discipline or a closely related group of disciplines.
Office Facilities (300 series)	Offices and conference rooms specifically assigned to each of the various academic, administrative, and service functions.
Study Facilities (400 series)	Study rooms, stacks, open-stack reading rooms, and library processing spaces.
Special Use Facilities (500 series)	Military training rooms, athletic and physical education spaces, media production rooms, clinics, demonstration areas, field buildings, animal quarters, greenhouses, and other room categories that are sufficiently specialized in their primary activity or function to merit a unique room code.
General Use Facilities (600 series)	Assembly rooms, exhibition space, food facilities, lounges, merchandising facilities, recreational facilities, meeting rooms, child and adult care rooms, and other facilities that are characterized by a broader availability to faculty, students, staff, or the public than are special use areas.
Support Facilities (700 series)	Computing facilities, shops, central storage areas, vehicle storage areas, and central service space that provide centralized support for the activities of a campus.
Health Care Facilities (800 series)	Facilities used to provide patient care (human and animal).
Residential Facilities (900 series)	Housing facilities for students, faculty, staff, and visitors to the campus.
Unclassified Facilities (000 series)	Inactive or unfinished areas, or areas in the process of conversion.
Circulation Area (WWW series)	Nonassignable spaces required for physical access to floors or subdivisions of space within the building, whether directly bounded by partitions or not.
Building Service Area (XXX series)	Nonassignable spaces used to support its cleaning and public hygiene functions.
Mechanical Area (YYY series)	Nonassignable spaces of a building designed to house mechanical equipment and utility services, and shaft areas.

BIM uses are classified based on the purpose for implementing BIM throughout the life of a facility. A BIM use is defined as “a method of applying Building Information Modeling during a facility's lifecycle to achieve one or more specific objectives" (PSU-The Uses of BIM, 2013) The purposes and characteristics of a BIM Use can be seen in Figure 2 below.

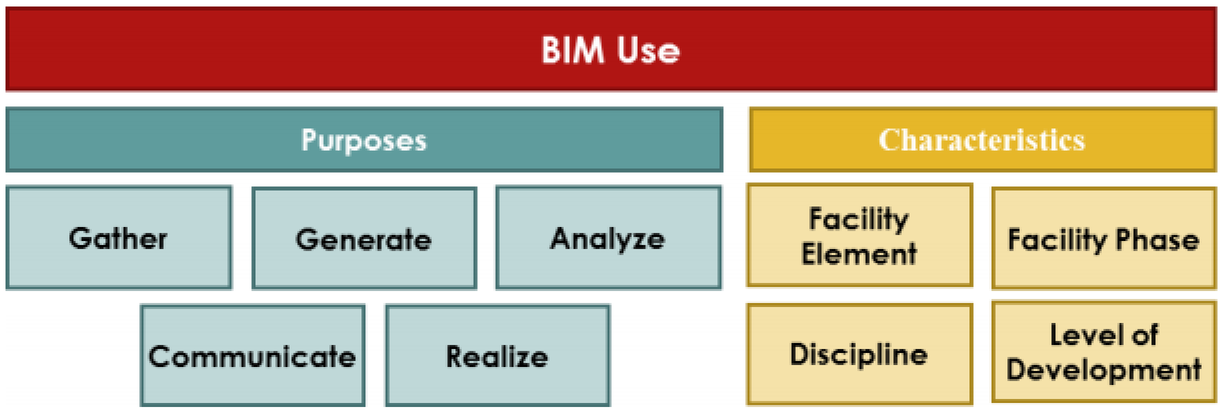


Figure 4: The Components of a BIM Use

[Source: PSU-The Uses of BIM]

The BIM Use purpose is to communicate the primary objective of implementing the BIM Use. A BIM Use has different purposes which fall into five primary categories: gather, generate, analyze, communicate, and realize. Each primary category as shown in Figure 3 has numerous subcategories which further specify the purpose of a BIM Use.

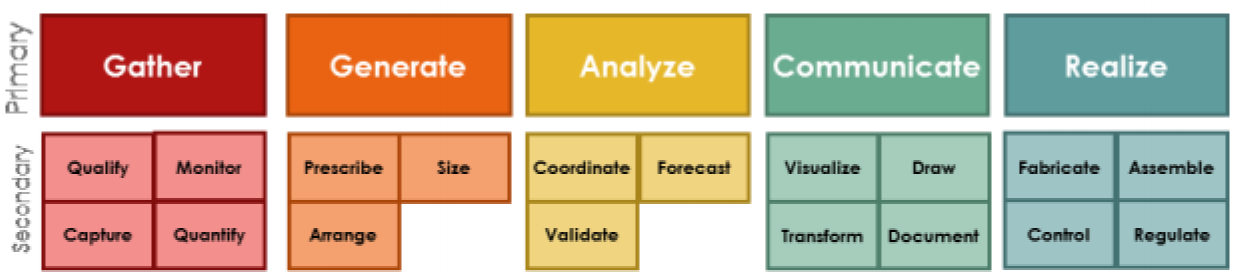


Figure 5: Purposes of BIM Use

[Source: PSU-The Uses of BIM]

2.5 Record and As-built Building Information Model

The availability of a record building information model with FM BIM guidelines is useful for the continuing operations and maintenance of the building. The record documents are the final deliverables from the architect, and the as-built documents are the builder's deliverables. This can be a combination of both traditional as-built drawings and record drawings fully populated with data. This contains information like 2D drawings, 3D model, and assets like furniture, furnishings, signage, security, and equipment specifications. This information is not typically submitted through the designer and builder BIM models but when contractual provisions are made in advance BIM data and graphic models can then be used to manage space, anticipate maintenance needs, provide information for remodeling and retrofitting, successful operation of a facility.

2.6 BIM Execution Plan (BEP)

A BIM execution plan (BEP) is a formal document that defines how the project will be executed, monitored, and controlled with respect to BIM (BIM terminology). It is a very comprehensive document that helps the project teams identify and execute the role BIM plays through the various phases of construction management. It outlines the overall vision along with implementation details for the team to follow throughout the project. A BEP is developed at project initiation stage, developing continuously as additional participants are added, and the project is updated, monitored, revised throughout the implementation phase of the project.

The BEP should define the scope of BIM implementation through the project, identify the process flow of BIM tasks, define the deliverables expected and describe the project and company infrastructure needed to support the implementation. It is a major component of the BIM guidelines document which defines project specific goals whereas the BIM guidelines are a standard institution based document. Developing a BIM execution plan helps the project and project teams achieve the following value (BIM Planning Guide for Facilities Owners, 2013):

- It helps organizations and participating parties understand the roles and responsibilities in the implementation process.
- It assists all parties in clearly understanding and communicating strategic goals for implementing BIM on the project.
- It helps the team tailor an execution process that is well suited for best business practices and organizational workflows.
- The plan guides any future parties with detailed description of the process.
- It is beneficial in drawing contracts and language essential such that all project parties fulfill their obligations.

Through this process, ultimately the entire team adds value through the increased level of planning by reducing or eliminating unknowns in the implementation process, thereby reducing the overall risk to all parties and the project itself.

2.7 Building Information Model – FM Database links

The BIM model can be used to efficiently provide information to continuously update the FM database and for managing assets. Information with detailed specifications can be made available in the form of spreadsheets, and the facilities can be connected to BIM.

As a part of efficiently updating the database of assets, the Construction Operations Building Information Exchange (COBie) approach was developed to address the lack of standardization and organization of the several documents that are handed over to the owner at the end of the construction stage. In the COBie approach, data is entered in a pre-specified format as it is created during the design, construction, and commission phases. Figure 6 Illustrates the COBie process overview.

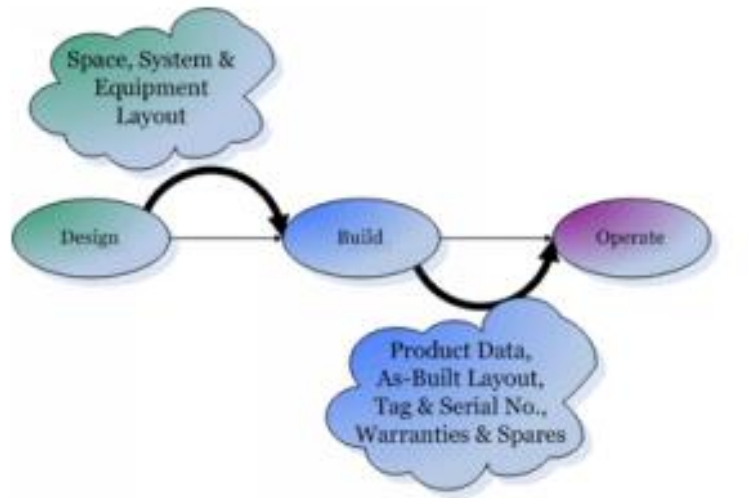


Figure 6: COBie process

[Source: East 2007]

COBie helps capture information through the various stages of the construction process. When the design stage concludes, construction documents, materials, products, equipment are all captured by COBie. During the construction stage, any submittals by the designer are digitally documented and linked to their respective systems. When the components are installed, all the related information is added to COBie which includes brand, model, serial number, and warranty information.

2.8 Use of BIM data for maintenance and Retrofits

Once a building or facility is constructed, repair and preventive maintenance requires a database of what exists and when the equipment needs to be fixed, upgraded, or replaced. This requires an accurate information FM database typically found in the

Computer Maintenance Systems (CMMS's). For example, if a building requires changing of lighting fixtures, the location of the fixtures, characteristics of the fixtures, and links to manufacture sites typically available for work order execution can all be fed into or extracted from the BIM model. Maintaining a BIM file for facility management requires simultaneous updates as the maintenance of the actual building. If any components are replaced, repaired, removed, those changes will need to be updated in the BIM file.

In the case of WPI, majority of the campus buildings were built before BIM was implemented on campus. BIM models can be linked to CMMS when new buildings are built or when BIM models are created for the existing buildings.

2.9 Need for a BIM guide

The utilization of BIM beyond design and construction is extremely important to provide an owner value for a facility through efficient FM operations. Currently, utilization of BIM at FM stage is not fully realized and is a relatively new concept for the FM department at WPI. The purpose of the BIM guide is an effort to bridge the existing gap by standardizing processes and integrating the facility operations in the design stage for new buildings. For existing buildings, BIM models should be created and data needs to be integrated for facility management. This will help extend the implementation of BIM into the later stages of the project life cycle. The project life cycle includes planning, design, construction, operation and maintenance, and decommissioning. Through BIM, it is possible to provide a framework to develop data rich models. These models will benefit a facility and serve as gateway to provide any time access to insert, extract, update, and modify data by all participants involved in the life cycle.

Integration of BIM through the design and construction process and extending it through the lifecycle of the project has the following benefits:

- Budget Management
- Contract Management
- Decision Making
- Information Management
- Material and Equipment Management
- Project Management
- Quality Management
- Resource Management
- Risk Management
- Safety Management
- Schedule Management
- Value Management

2.10 Objectives of the guide

Since 2005, WPI has been using some components of BIM in the design and construction of new facilities and has extended BIM uses to support facilities and space management in some of the existing buildings. An effort to implement BIM has been extensively observed and studied through student projects and theses on campus. The students have worked with the FM department on various projects but current BIM practices for WPI campus are not consistent and sustainable in their current form. To date, no formal and systematic approach has been established in documenting and organizing processes for the different BIM uses on campus.

The main objective of this guide is to provide the requirements and technology for WPI's use of BIM for facility management. It aims to meet several purposes:

- Identify the work processes and information requirements for facility management.
- Determine the information required before, during and after construction.
- Evaluate different methods to record and capture information updates.
- Define the scope of information that should be included or updated at the end of a project.
- Identify technology requirements to access and update the BIM data by the architects, contractors, and facility managers.

  This guide will help to provide better maintenance of the campus and coordinate the different facilities on site. Whether it is new construction or an existing old building on site, these guidelines will list the scope of work and deliverables for projects on campus.

3 METHODOLOGY

To attain the objectives of this research, the following methodology was identified for delivering a successful BIM guide:

- Conduct a case study on the Facilities Management process.
- Conduct in depth case studies of existing university BIM guides and review existing documentation published by other universities.
- Develop a proposal for a BIM guide exclusively for WPI.
- Validate the contributions of the proposed BIM guide.

3.1 Conduct a case study on the Facilities Management process

One of the key aspects of proposing a BIM guide is to have a good understanding of the Facility Management processes and operations. To achieve this, an in-depth case study consisting of two major parts was conducted on campus at WPI. The first part of the case study analyzed the Facilities Management organization and identified the different activities undertaken by the department. To facilitate this task, a study of the organizational chart and interactive meetings with the department were conducted. This helped better understand the relevance and importance of BIM in the current processes at WPI. It gave an insight into the Computerized Maintenance Management System (CMMS) system that the department utilizes for campus management. The main goal of this study was to identify how BIM has been a part of campus planning and management in the past and how relevant is it to the department moving forward.

The second part of the case study was to study the role of BIM in completed and ongoing projects on campus. The WPI Recreation and Sports Center, a facility completed in 2012 was selected to study a completed project on campus that, to a certain extent used BIM in the design and construction of this facility. The key idea was to analyze how the BIM process was implemented by the architect and the construction manager for the design documentation and coordination, as well as for providing information delivered at close-out for the building. This information was used to analyze the relevance of BIM and its benefits to the FM department.

For an ongoing project on campus, a case study was conducted on the Foisie Innovation Studio. This looked at the benefits of utilizing BIM as a tool for managing and facilitating construction from the design phase onward. The main purpose of this task was to identify the benefits of incorporating BIM early in the project that could benefit the FM department later for operation and maintenance.

To date, 25 BIM models were created as part of student projects from data available. The following buildings were modeled in detail after verifying information in field:

- Project Center
- Washburn Shops
- Salisbury labs
- Institute Hall
- Sanford Riley Hall

- Founders Hall

The attributes that were of main interest to the participating facilities staff were linked to the spaces in the BIM.

3.1.1 Interviews

A set of interviews was conducted in which six (6) key members of the facilities management team were consulted to identify their requirements for information and to identify potential ways in which they would like to utilize BIM for facilities management. Their responses about the need and relevance for the development of a BIM guide for WPI were recorded – Table 2 (Pg. 94) summarizes the results of these interviews.

3.1.2 Research

Worked with the FM department to understand their needs and requirements. Consultation through presentations and interviews helped identify goals and draw a work plan to move forward with the research. Collected data on the case studies and studied successful BIM implementation for large campuses/universities. Identified best practices and BIM information relevant to WPI.

3.1.3 Survey

Any work done on campus with respect to BIM has been through student projects done with the Facilities Department. A survey of these existing measures implemented on site through student projects was conducted to review the nature and depth of the work undertaken.

3.1.4 Proposal

The survey not only helped identify what was implemented on campus, but also determine the nature of problems, identify requirements and what proposals/guidelines can be identified for WPI. The proposal would address specific BIM needs.

3.1.5 Priorities

Developing the proposed content required setting what actions are most important and prioritize goals as all prior solutions for all findings from the research may or may not be incorporated in the proposed guide.

3.1.6 Design

The final step was to develop and design the BIM-guide that met the WPI needs and requirements in assisting BIM implementation on campus for facility management.

3.2 Conduct a case study of existing university BIM guides

A case study of existing university BIM guides was conducted to understand the different uses of BIM, fields of applications and the targeted users through five university BIM guides that have been successfully adopted and implemented. The key method of the research was to use a template approach to determine a baseline of common fields from majority of the BIM guide documentation available. A template approach was used to structure the review of a document and allows for systematic comparison of the contents and scope of different guides.

Due to the lack of standardization at national or international level (NBS International BIM Report 2016), this analysis is used to harmonize the content of the guides at various levels:

- Different uses of BIM and fields of applications and the targeted users.
- Map content by the given chapters to derive a common table of contents. This establishes a common structure of framework which aids the process of creating a new BIM guide.
- Mapping definitions and terminologies; these keyword help identify and standardize terminology that contributes to establish a measure guide with consistent or standardized terms, definitions, and structure.

The study helped map the contents by the given chapters and derive a common table of contents for the proposed BIM guide. Though the guides were different in some ways, several commonalities were observed in all five. This helped establish a common structure of framework which aided the process of creating the new BIM guide. It also helped map common definitions and terminologies; these keywords helped identify and standardize terminology that helped contribute to the made to measure guide with consistent, standard terms, definitions, and structure.

3.3 Develop a proposal for a BIM guide exclusively for WPI

The detailed analysis of the case studies helped identify the following common categories of information type:

- Standards
- Contracts specified (including technical specifications)
- Roles and responsibilities of involved parties
- Tools & technology

- Modeling guidance

This helped identify how to plot content towards adopting relevant data and mapping the common table of contents for the proposed BIM guide. The outcome was to propose and develop BIM guide for WPI facilities management department.

3.4 Validate the contributions of the proposed BIM guide

For the purposes of technical feasibility and reliability, the BIM guide proposed in this research was validated in two parts: The first part validated the document feasibility by looking at the value added using BIM guidelines by applying the proposed concept to one of the pilot projects on campus for FM purposes. The Project Center building was selected for the validation process.

The second part was a documented form of feedback from the facilities management staff through presentations and personal interviews. Six members of the facilities management team participated in the interview process and completed a questionnaire (see Appendix A). The interviews addressed various questions like need for the guide, feedback on the proposed contents of the guide, identify missing content, potential users of the guide, relevance of the guide for FM for new and old buildings, etc.

4 WPI FACILITIES MANAGEMENT PROCESS

The key to propose a successful BIM guide for the WPI FM department is to understand the FM processes and operation. To achieve this, a study was undertaken to better understand what are the main functions and organization of the FM department and how is the FM department currently using BIM in new and existing projects.

4.1 The Facilities Management department

This section looks at the organization of the FM department, their efforts to implement BIM on campus and the integration of BIM in the construction process for existing and new construction.

Facilities Management department organization:

Worcester Polytechnic Institute (WPI) was founded in 1865 and houses 14 academic departments that offer over 50 undergraduate and graduate degree programs. The campus is located on a 95-acre site set in an urban context in Worcester city. It is a private institution with an enrollment of 4,320 undergraduate students, 2,063 graduate students and faculty strength of over 450 members. (WPI 2016)

The campus has 36 major academic, residential, recreational, and administrative buildings encompassing nearly 2,394,471 gross square feet (GSF) of space. In addition to the buildings on the main campus, WPI owns 38 houses and a 24-unit apartment building in the neighborhood (WPI STARS report, 2015).

The Facilities Department plays an important role in the operation and maintenance of the campus on a day-to-day basis. Their following mission statement conveys the main functions and commitment of the department towards the WPI community.

“The mission of the Facilities Department is to provide a safe, clean, properly maintained environment for the WPI community, in support of academic and social activities. Facilities staff will furnish the highest quality service, with the highest level of professionalism.” (WPI Facilities Department)

The organizational chart of the department as its highest level is shown below in Figure 7

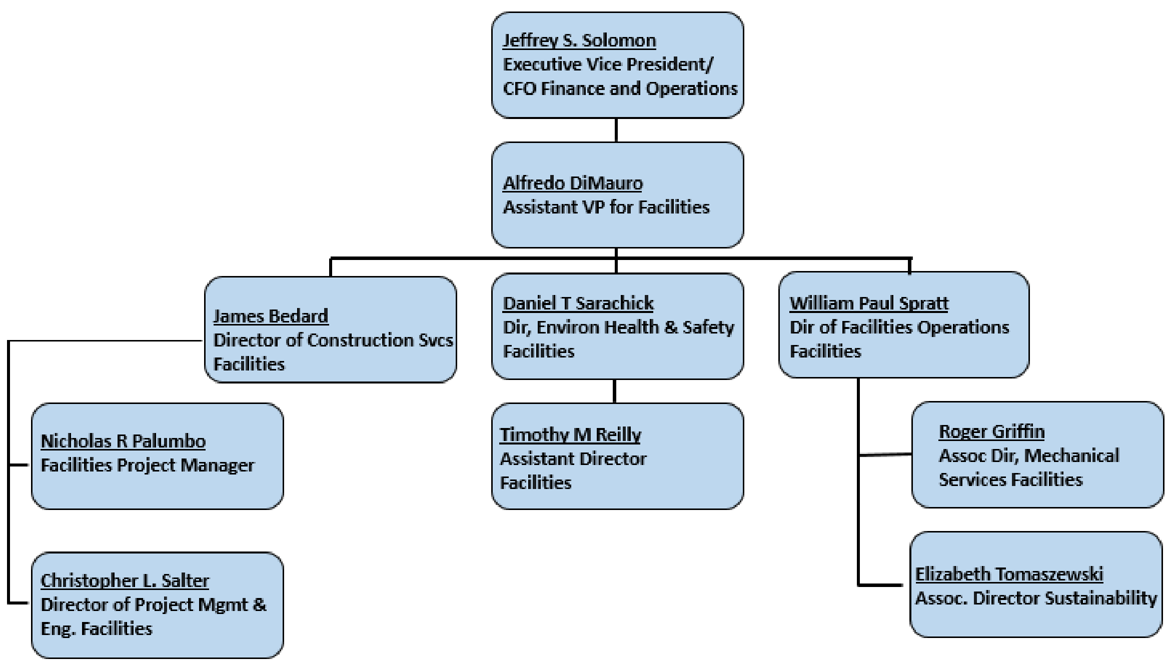


Figure 7: Facilities Department Organization Chart

4.2 BIM uses for FM at WPI: Existing Facilities

Space Management, one of the major functions of the FM department, is an activity that is naturally supported by BIM. WPI first adopted BIM in 2005 and since then it has been gradually explored and implemented in various aspects of design, construction, and facilities management of some buildings on campus as well as for academic purposes. WPI adopted the use of Revit to build BIM models of existing and new buildings on campus to assist with better campus management. To date there are 25 BIM models of campus buildings that have been mostly developed as student projects to different degrees and for different purposes. These models contain information that can be used for space management, operation and maintenance, attributes assigned to spaces and the location of MEP equipment.

The BIM models were intended to be used during the lifecycle of a construction project, operation, and maintenance. Repeatedly, facilities department has acknowledged the benefits of utilizing BIM for FM. For example, an incident that occurred during a baseball match at Harrington auditorium broke a fire sprinkler causing water leakage. Unfortunately, it took the facilities department a while to locate the shut off valve causing inconvenience to everyone. BIM data could have helped located these utilities and shut off valve to respond to the emergency faster.

The development of BIM models as a part of student projects was an effort to build models of the existing buildings on campus. These buildings did not necessarily have updated plans and drawings to begin the BIM process but the models were built off what was available. The BIM models created by the students contain primarily the architectural floor layouts and in some cases the structural frame of the building. In 2013, the FM department initiated a more aggressive use of BIM and selected few buildings to study the benefits of application of BIM in more detail. To start with, small and less complex buildings like the Project Center was selected and modeled.

4.2.1 Work done so far

The buildings worked on so far on campus are the Project Center, Washburn Shops, Salisbury labs, Institute Hall, Sanford Riley Hall, and Founders Hall. These are existing buildings on campus, and BIM models were developed to better manage and maintain by the Facilities Department.

Through interviews with FM staff, the following attributes of interest were identified in the BIM model to analyze the use of floor area. These attributes are:

- Room Number
- Gross Area
- Net Usable Area
- Net Assignable Area
- Floor Finish
- Number of Work Stations / Capacity
- Use of the space (type)
- Space assignation (department)

The Postsecondary Education Facilities Inventory and Classification Manual (FICM), 2006 Edition manual describes standard practices for initiating, conducting, reporting, and maintaining a postsecondary institutional facilities inventory. Space is one of the primary resources of an educational institution. The FICM provides definitions of building area measurements, space use codes, room use codes and data useful for including in a facilities inventory. It provides guidance on required and optional data for inclusion in a facilities inventory, guidelines for developing a facilities database, suggests administrative and analytic uses for facilities data and presents issues that emerge in collecting, maintaining, and reporting facilities data. A more detailed description of these parameters is presented in section 4.2.3. Figure 8 below shows the first floor of the Salisbury Labs building BIM model indicating color coded space use categorization as per FICM.

Figure 8: Sample view of Salisbury model

4.2.2 Process of creating BIM for buildings at WPI

The following procedure was adopted for all selected buildings on campus for the implementation of BIM.

1. Retrieve and digitize the drawings for the buildings:

For the selected buildings, any existing CAD or paper drawings for the buildings were used. There were differences between the available as-builts and the existing facility, as renovations were mostly never updated on the drawings. The files were imported into the BIM tool (Revit) and used as a starting point for the creation of the model. The BIM tool used was Revit. Figure 9 below indicates how the 3D model is built from the 2D drawing.

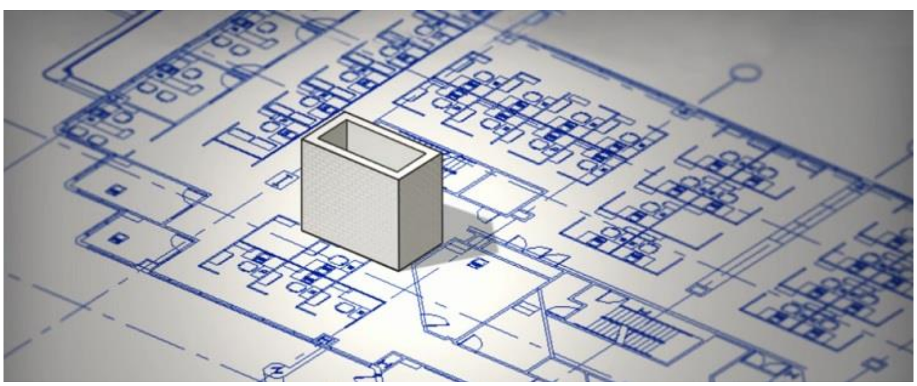


Figure 9: Migrating from CAD to Revit

[Source: https://i.imgur.com/aysVKsS.jpg]

2. Verify the dimensions of the available drawings:

The existing drawings were verified by taking field measurements of the actual facility, using a laser distance meter. A tape measure was used where the use of the laser was not feasible. Photogrammetry techniques and laser 3D scan part of the campus, created by a third-party consultant, were also used to verify external measurements of some of the buildings

The use of laser scanners to measure a building is a new and emerging technology, though expensive but very effective and accurate. It uses a device, shooting beams of light, and measuring the distance and angle of the reflection of light, which can perform thousands of measures per second, and each measure is a referenced point that after processing can be combined in a point cloud creating a three-dimensional representation of the facility formed by points. The model produced, once the point cloud file is imported into the BIM model has high accuracy and is especially convenient for modeling existing buildings and their MEP systems, exterior envelopes, etc.

3. Develop the model:

After verifying the dimensions of the drawings, the model was created which included the geometry and basic information of the modeled elements. The model included walls, floors, fenestrations, roofs, and stairs. No structural, mechanical, plumbing or electrical systems were modeled. These systems were indicated and their locations were mapped for representation purposes.

4. Create spaces:

The models indicated rooms were created representing the different spaces in the facility enclosed by walls and floors. The space calculation was set to volume, therefore not only the area of the room is available but also the volume

5. Attach important information to the model rooms:

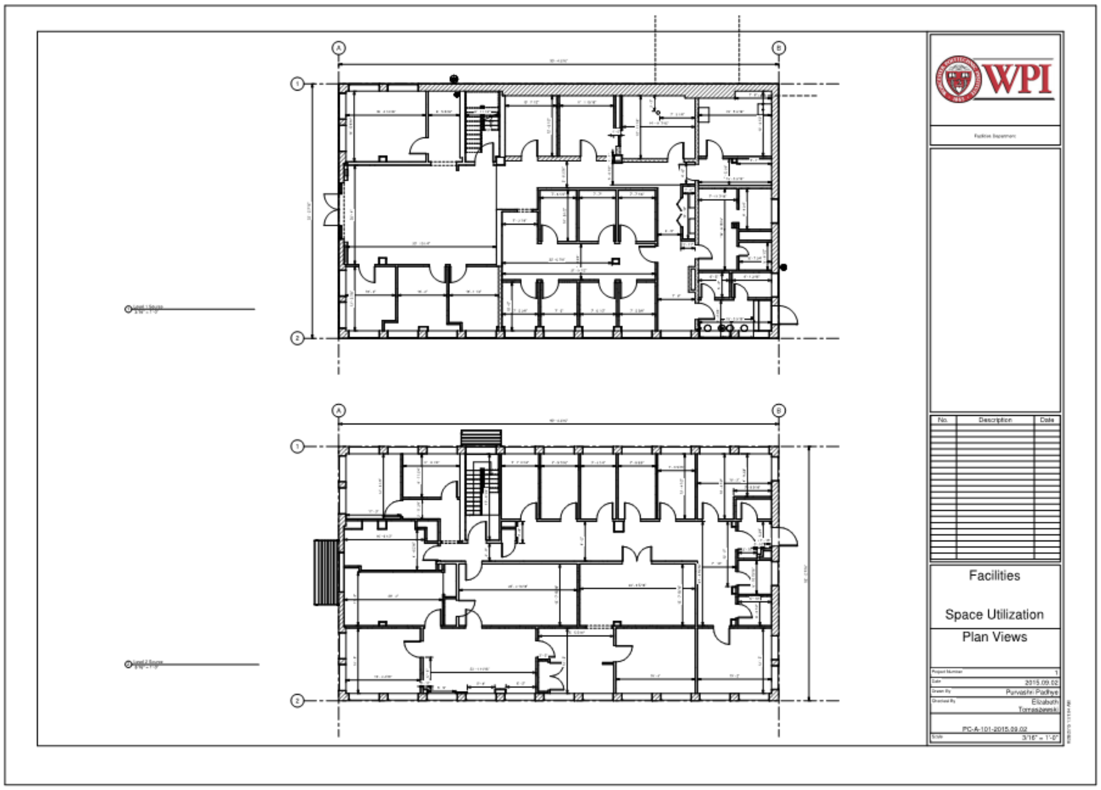
The different information associated with the rooms was integrated in the model. This information included area, location, floor finishes, ceiling finishes, room capacities, and the location of the connection of the building with external MEP utilities. This information was documented directly from the facility at the same time the dimension verification took place. The FICM classification was used to classify the use of space.

6. Finalize BIM model:

The actual BIM model was created in Revit and a viewable version of the 3D model in DWF format as well as 2D floor plans using a drawing sheet template in PDF format were created and distributed to the users. Both formats were not editable. The DWF file can be used for viewing and interrogating the model. The following information was included on the PDF drawing sheet template:

- Original issue date
- Sheet number
- Title - description of drawing and location information.
- Location information should include all building, floor, and room numbers as applicable.
- Scale of the drawing.
- Revision history - as applicable.
- WPI Project number.
- Information on who has drawn the drawing and who has reviewed the drawing.

An example of the final drawing produced is shown in Figure 10 below.



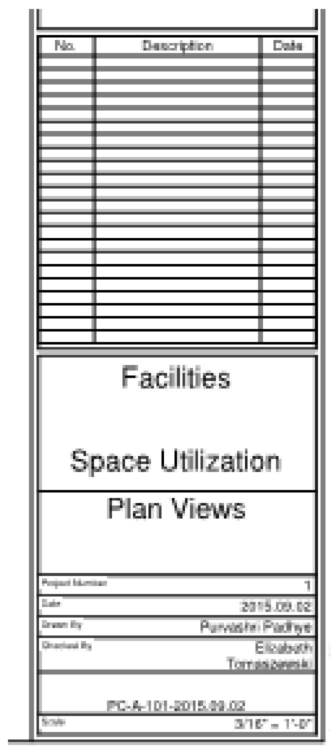


Figure 10: Sample of the drawing sheet

7. Uploading and storing BIM files:

The final BIM files were stored on the SharePoint website: https://sharepoint.wpi.edu/research/bimfm/documents/

SharePoint is a collaboration tool that allows teams to share documents, contacts, calendars, and other relevant information on one website. The Facilities Department helped provide access to the FM BIM files and one could use their WPI credentials to log in to the portal. All BIM related information/data was stored under the student projects tab and this information was accessible only to authorized personnel's. The SharePoint application was also available to download on all Android and Apple devices through the App stores making this data easy accessible. The app was free to download and the user could view all pdf files available on SharePoint on their mobile devices on the go.

4.2.3 Different model parameters

The model parameters specified above were the key information that the WPI Facilities department found most relevant. The selection and relevance of these were derived from the interviews and interactions with the facilities department staff.

- Department: A department consists of various room that encompass the different spaces that were included in BIM. This was used to allocate costs, return on investment analysis by the facilities department. The department listing information was obtained from the buildings directory.
- Room numbers: The room numbers were required for room identification and the WPI numbering system was adopted. The room number is a three-digit number

with the first number indicating the floor number and the other two digits indicating the room on the floor. These room numbers were verified with the actual ones in the facility. The room numbers at WPI are always three digits, the only exception being Gateway Park, where there are four numbers. (WPI Acronym Dictionary)

- Room areas: The room area is an important aspect of space management. It helps to understand the allocation of spaces for various uses such as, departments, staff, students. The room areas were calculated directly from the model having verified the dimensions beforehand. These areas were calculated based on the clear interior dimensions of the rooms. This information is of great value not only for the FM department but for other WPI academic and administrative purposes as well.
- Floor finishes: Floor finishes were another attribute added to the BIM which would mainly be used for custodial coordination. This also helped identify the floor finishes assigned to the spaces in a facility.
- Ceiling finishes: Ceiling finishes served the same purpose as the floor finishes. These attributes helped update information that was outdated as there was renovation done over the years on these buildings.
- Room use: The room use attribute helped determining room capacities, efficiency rating and future possible uses. The projects implementing BIM at WPI used the WPI standard for door tags and the Post-Secondary Facilities Inventory and Classification Manual (FICM) (National Center for Educational Statistics, 2006) for

space categorization. Figure 11 below elaborates on the space categorization per the FICM.

100 Classroom Facilities
- 110 Classroom
- 115 Classroom Service

200 Laboratory Facilities
- 210 Class Laboratory
- 215 Class Laboratory Service
- 220 Open Laboratory
- 225 Open Laboratory Service
- 250 Research/Nonclass Laboratory
- 255 Research/Nonclass Laboratory Service

300 Office Facilities
- 310 Office
- 315 Office Service
- 350 Conference Room
- 355 Conference Room Service

400 Study Facilities
- 410 Study Room
- 420 Stack
- 430 Open-Stack Study Room
- 440 Processing Room
- 455 Study Service

500 Special Use Facilities
- 510 Armory
- 515 Armory Service
- 520 Athletic or Physical Education
- 523 Athletic Facilities Spectator Seating
- 525 Athletic or Physical Education Service
- 530 Media Production
- 535 Media Production Service
- 540 Clinic
- 545 Clinic Service
- 550 Demonstration
- 555 Demonstration Service
- 560 Field Building
- 570 Animal Facilities
- 575 Animal Facilities Service
- 580 Greenhouse
- 585 Greenhouse Service
- 590 Other (All Purpose)

600 General Use Facilities
- 610 Assembly
- 615 Assembly Service
- 620 Exhibition
- 625 Exhibition Service
- 630 Food Facility
- 635 Food Facility Service
- 640 Day Care
- 645 Day Care Service
- 650 Lounge
- 655 Lounge Service
- 660 Merchandising
- 665 Merchandising Service
- 670 Recreation
- 675 Recreation Service
- 680 Meeting Room
- 685 Meeting Room Service

Figure 11: FICM Space categorization

[Source: FICM, 2006 Edition]

4.2.4 Use of the model:

The target users of the models were identified as members from the facilities department and administration. The idea was to create a user-friendly format that could be easily accessible by everyone. Interviews with the users (Appendix B) clearly indicated that users preferred 2D representations of the models in PDF format instead of 3D Revit models that could be accessed on a mobile device such as a tablet, computer, or a smart phone. They expressed that the 3D model representation was good to visualize the project but navigating and managing the model required knowledge and expertise of the software. The PDF format of the files only permitted viewing the files which ensured that the files would be non-editable. These files would be accessible through the SharePoint website and access would be controlled.

4.2.5 Maintenance of the model

To ensure successful and continuous implementation of BIM, updating information on the model is important. Every time a facility undergoes renovation, the model must be updated. This would require updating the last and latest version of the model available following the proposed guidelines listed in the WPI BIM guide in Appendix C. The FM department must appoint an individual, who could be a designated FM staff member, student assistance or third party consultant with the knowledge of BIM and the work done at WPI to update the models. These models should be updated periodically to record for any updates, changes, retrofits. An up-to-date BIM model will help in renovation, quantity take off, cost estimation, campus planning, future construction, operation, and maintenance. The BIM software, Revit can be used to update the models and make information available to users.

4.3 BIM uses for FM at WPI: New facilities

The section presents two case studies to illustrate the existing BIM processes adopted and implemented at WPI on their new buildings. Two buildings were selected to complete the study, one recently completed building and another building under construction. The completed building was the WPI Sports and Recreation center and the building under construction was the Foisie Innovation Studio. Information on both these projects was obtained from student project work done for both the building on campus for BIM.

4.3.1 Case Study 1: WPI Sports and Recreation Center

The WPI Sports and Recreation Center is a 140,000-square foot recreational, educational, and environmentally friendly facility. It contains a pool, a fitness center, a four-court gymnasium, an indoor running track, rowing tanks, racquetball and squash courts, dance studios, and offices and meeting spaces for the coaches and staff of the Department of Physical Education, Recreation, and Athletics. The Sports & Recreation Center is home to the wrestling team as well as the practice facility for men's and women's rowing and varsity team training.

Construction of the WPI Sports and Recreation Center was completed in 2012. This was the first project in which the architect submitted a BIM model but only for the purposes of generating the construction documentation (See Figure 12). The student project (Alvarez, 2014) explored the use of BIM as a tool to provide continuity for the flow of information from the design/construction phase to the operation and maintenance phase by the WPI Facilities Department. Through student academic projects, the importance of implementing BIM A model was created to demonstrate the capabilities of BIM for architectural, structural data, for storage and retrieval of closeout documents, operations and maintenance manuals, all information critical for the Facilities department.

Figure 12: Completed WPI Sports and Recreation Center Background

[Source:http://www.pci.org/uploadedImages/Siteroot/Project_Resources/Project_Profiles/Profile_Pages/WPI_Pao.JPG]

4.3.1.1 Project Organization

Several parties were involved with the design and construction of the Recreation Center. An organizational chart with the main parties that constituted the project team is shown is figure 13. The construction manager for the new center was Gilbane Inc., Cannon Design was the design firm for the new center and the owner's project manager was Cardinal Construction.

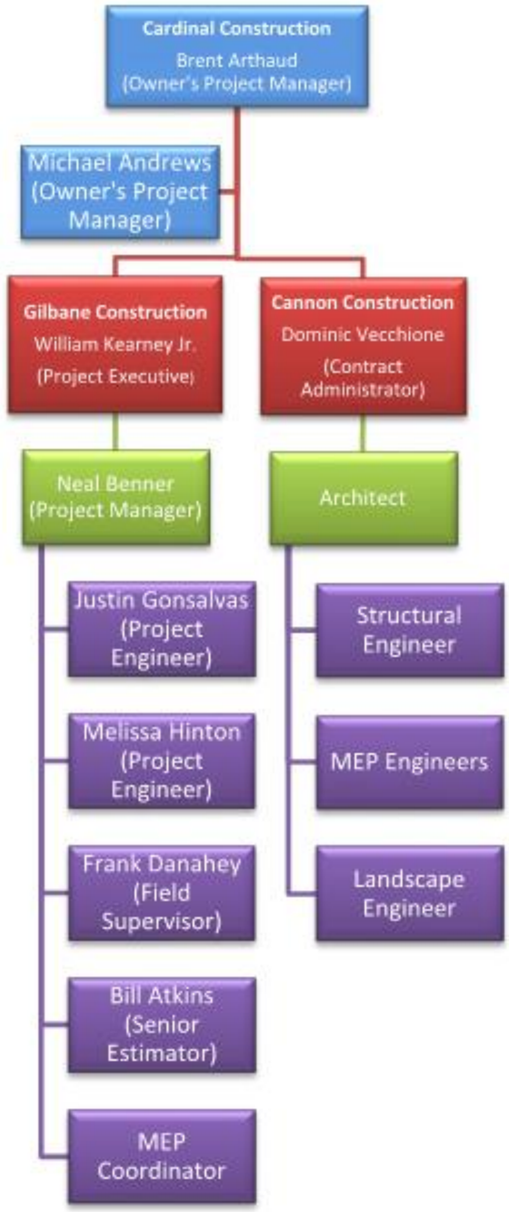


Figure 13: External Organization Flowchart

[Source: Trevor Bertin et al, 2011]

4.3.1.2 Architectural and Structural Design

The availability of the BIM model for the project gave WPI students and faculty an opportunity to explore structural materials and design alternatives whilst providing calculations and cost for each alternative. This helped identify the most cost effective alternative in the long term. The use of 3D modeling helped visualize design features and evaluate what was aesthetically most pleasing at the early stages of project development. Though the record model was developed using Autodesk Revit, the file was viewable through Autodesk Design Review software. The record model did not contain the design changes that took place during construction. However, having the 3D model in DWF format gave easy access and operability to the Facilities Department as it was a user-friendly interface that didn't require intensive training to use. The DWF files associated with the software were significantly smaller that the Revit RVT files. This allowed for convenient storage and transfer of information.

4.3.1.3 Cost and Schedule

Based on the architectural BIM, the construction manager created a 3D Navisworks model to coordinate the MEP work prior to the execution of this work. This allowed the contractors to anticipate system clashes and prepare cost estimates for the different alternatives. This helped review and compare costs to determine the most cost efficient solution. Also, schedule estimates for each of the alternatives were produced using information obtained from the BIM model.

4.3.1.4 Facilities Management

The operations and maintenance (O&M) manuals and other closeout information were conveyed through the 3D as built drawings that were relevant for FM. The model included MEP systems, structural and architectural elements. A PhD thesis (Alvarez, 2014) was dedicated to study what information from the BIM model was of use to the FM and how the information contained in the BIM models could be used for FM purposes. The main contractor delivered this information in a digital format on a DVD and was organized by CSI trades. The package included a total of 540 files, however, only 442 files contained useful information. It was observed that there was redundancy in the information in terms of drawings stored as PDF and DWG format. The submitted drawings included Bidding and As-Builts documents showing some inconsistencies in room numbering and levels. The names of the files were very short with no clear indication of what was included in the drawing.

The remaining documents comprised of Operations and Maintenance (O&M) Manuals, Specifications, Warranties and Guarantees. However, these documents were not organized, were different types and not indexed making future queries for information very time consuming. A BIM model developed by the designer only for project visualization, presentation purposes and production of coordinated 2D drawings was also handed over on this project. This original model was later updated by WPI students who modified the original numbering assigned by the designer to reflect the final assigned room numbers. Some elements that were not relevant to FM were filtered out thus creating a lighter version of the model for their use. The model parameter was modified to meet the requirements proposed by the FM department and was successfully structured with the added parameters in accordance with the IFC standard, combined with COBie and Owner specifications and linked to PDF scanned documentation using the proposed model view definition. The students research proposed an approach for making the documentation available for the FM users through a shared folder. However, much work on classifying and sorting information was still required to make the system truly functional. In addition, recommendations were made for structuring and standardizing the file management system. Overall, these studies provided in-depth understanding of the BIM based process and of the information needed by FM.

4.3.2 Case study 2: WPI Foisie Innovation Studio (New ongoing project)

The Foisie Innovation Studio will consist of residential and academic spaces with a total area of 78,000 square feet, with 40,000 square feet of academic space and 38,000 square feet of residential space. As WPI is getting more involved in BIM and having used BIM in the past on other projects, BIM would be an important aspect of this project.

The design and construction of the Foisie Innovation Studio (See Figure 14) is now being used to further advance the use of BIM at as a tool, that among other purposes, will coordinate the creation of information during design and construction transferred to the FM department when the construction is complete in 2018.

Figure 14: Proposed WPI Foisie Innovation Studio

[Source: https://www.wpi.edu/sites/default/files/2016/08/31/Foisie%20Renderings.jpg]

4.3.2.1 Background

WPI was founded in 1865 by two entrepreneurs from Worcester, Massachusetts, and has held true to its roots by maintaining a focus on innovation and collaboration. As illustrated by the school's motto, WPI students are encouraged to learn not only in the classroom, but by working on real-world projects. Boynton Hall and Washburn Labs are two buildings on campus that have served as symbols of the school's philosophy. WPI is now in the process of adding another building that will represent its philosophy: Innovation. Following the razing of Alumni Gym, WPI is making way for the new Foisie Innovation Studio that will complement the role of the Boynton Hall and Washburn Labs, while symbolizing the new addition at WPI.

Originally, Alumni Gym was the hub for athletics on the WPI campus. With the construction of the Sports and Recreation Center, there was no longer a need for this facility. Although the Foisie Innovation Studio will cater to different academic needs, an element of the Alumni Gym is retained to conserve the history of the gym building. The grotesques on the gym building will be incorporated in the design of the new building (see figure 15).

Figure 15: Grotesque on Alumni Gym

[Source:https://c.o0bg.com/rf/image_1920w/Boston/20112020/2016/01/13/BostonGlobe.com/Metro/Images/011316_wpifigure_08.jpg]

4.3.2.2 Application of BIM

The intent of the project was outlined by the Board of Trustees that elements of BIM were to be included early in the project to assist with coordination and interoperability amongst the design team, contractor, and owner, thus promoting collaboration. Therefore, the Request for Proposal for design and construction services for this facility required providers of services to be knowledgeable about BIM for the different stages of the project.

- Architectural design: The best way to understand the architectural design of a project is through visual displays. The architectural BIM model for the project provided a more comprehensive understanding of the design and acted as a platform for all involved parties to provide inputs and solutions. The model provided 3D views and architectural layouts with detailed floor plans which helped foster a spatial understanding of the building and assisting with visualizing the exterior appearance and context of the building with its surroundings. The architectural and interior layouts play a crucial role in communicating information about spaces, flow of people and activities through the building. The production of these views can be accurately achieved with the use of BIM. The process of finalizing these layouts and details goes through several iterations which can be easily and efficiently managed through BIM. The model also enables to virtually walk through the building which helps make comparisons to 2D layouts, thus identifying errors, additions, and omissions as the design progresses.

- Structural design: The structural component of the BIM software works in relation to the architectural component making it convenient to identify clashes between the architectural and structural members. The early detection of these clashes is an important aspect of the BIM as it helps deliver an accurate structural frame saving enormous amount of time and man-hours spent on numerous calculations and analysis after. The clash detection helps avoid potential design errors in field thus reducing construction costs to mitigate, avoid schedule delays and fewer requests for information (RFI's).
- Project Scheduling: One of the key aspects of the project was to create a schedule for the construction of the building that would verify the feasibility of the proposal within the constraints set by WPI board of trustees. With the start and end date defined, the BIM helped with identifying and arranging the activities in a logical

sequence. Primavera software assisted with a network diagram which assembled this information and helped determine the critical activities for the execution of the project. Utilizing BIM in the development of the schedule saves the contractors and designers a significant amount of time and money while also helping them visualize the project. Users can produce a 5D model (cost + time) which interconnects the 3D building model with cost and time. Scheduling provides a work breakdown structure that organizes the construction activities into sections/phases which simplifies the complex process of coordinating the various activities done at the same time on different sections of the building.

- Cost Estimating: The use of BIM allows for a deeper and more accurate analysis and evaluation of the project even before the project breaks ground. The total cost of the project was determined using a detailed breakdown of labor, materials and equipment for demolition, architectural and structural work. Including the cost in the 5D model helps visualize information in a comprehensive manner, it allows all involved parties to understand how the building will come together and what will be the value earned as construction progresses. It also illustrates how each additional element adds to the cost of the building and helps track the progress of the different phases of construction.
- Facilities Management: Currently, a student MQP project is being conducted to document the process by which WPI, the designer and the construction manager involved in the construction of the Foisie Innovation Center are coordinating FM related information from design to construction and handover to the owner

(Doskocil & Vaitkunas, 2017). The RFP documents used to invite design and construction professionals for this facility contained an explicit statement requiring BIM-based capabilities from these professionals. However, no specific terms were included in the contract to define the scope and extent of the use of BIM in the contract language. This resulted in a very interesting and collaborative process among the owner, designer and construction manager that has "forced" WPI to think critically as to what information, is really needed, what is not needed and what is desirable. This has also provided an opportunity to examine the role and desirable uses of BIM in this process.

Finally, specific information, structure, and content of data, including BIM-models to be handed to the owner at the completion of the project has been clearly defined. The students have played an important role in this process reviewing all previous work conducted at WPI to-date and in promoting the dialog among project participants. It has been agreed that the CM will incorporate building attributes with their corresponding information into the BIM model that are of primary interest to FM staff. This information, which is primarily of the MEP type will be part of the record model and will be exported into a spreadsheet feeding directly into WPI's CMMS system. Subcontractors are required to provide this information in their submittals.

4.3.3 Conclusion

The Department of Facilities purpose is to "broadly oversee the Institute's physical assets" and more specifically, "to maintain the adequacy and condition of capital assets, to develop and periodically review policies, to advocate for new structures and rehabilitate or remove older structures, and to make certain that adequate levels of funding exist for facilities maintenance and operations." (Department of Facilities, 2010)

Both the projects just reviewed looked at the benefits of BIM through student projects and had no contractual agreements for the projects. The Foisie Innovation Studio project has some contractual elements but were not clearly defined. However, the BIM requirements established by WPI and the collaborative approach observed during the design and construction of this project is further advancement of the use of BIM for FM purposes. The key idea of implementing BIM on the project was to aid in the maintenance and operation of a facility and its assets throughout the lifecycle of a building. This helped assist in short-term operations like work orders, repairs, and long-term preventive maintenance. The BIM record documents provided an accurate representation of the physical conditions and assets of the building. It contained all detailed dimensions and closeout information for the facility, MEP utility systems and equipment. This information has assisted the Facilities Department in the following:

- Maintain and update facility and equipment data.
- Document and maintain O&M user manuals and equipment specifications.
- Analyze and process work orders by retrieving the relevant information required to complete the work.
- Track usage, performance and maintenance of the facility and its assets.
- Easily update the record BIM in case of upgrades, renovations, and maintenance.

- Access BIM data digitally on desktops, mobile devices, tablets to locate issues, monitor equipment, look up floor and ceiling finishes, and calculate areas without physically visiting the facility.
- Data is secure and can be accessed only by authorized personnel's.

5. CASE STUDIES

A review of the material published by the five institutions was conducted to learn what other universities around the country have done with regards to the development of BIM guidelines at their institutions. Following are the five selected case studies (see Figure 16):

1. Case study 1: Indiana University (IU)
2. Case Study 2: Pennsylvania State University (PSU)
3. Case Study 3: Massachusetts Institute of Technology (MIT)
4. Case Study 4: Georgia Tech University (GTU)
5. Case Study 5: University of Southern California (USC)

[THIS SPACE HAS BEEN INTENTIONALLY LEFT BLANK]

Figure 16: Map of United States showing case study locations

The above case studies across United States were selected because of their comprehensive nature and successful applications to different projects on their respective campuses.

5.1 Identify information for Comparative Analysis

The approach followed to analyze these cases consisted in identifying common categories of information type, implementation strategies and to plot that content towards adopting relevant data for WPI. The idea was to use a template approach to determine a baseline of common fields from majority of the BIM guide documentation available. A template approach was used to structure the review of a document and allows for systematic comparison of the contents and scope of different guides. The different categories broadly identified were standards, contracts specified (including technical specifications), roles and responsibilities of involved parties, tools, technology, modeling guidance. Most of these categories were relevant to all five BIM guides cases.

5.2 Review guides for common data fields

The selected guides were reviewed to capture common data fields which would provide a method by which a comprehensive comparison would be possible. The various BIM guides were very diverse in their content and the intent was to capture common elements of the guides. The documents were split into two major sections with multiple sub-sections:

<u>Section 1: Guide Overview</u>

Part a – Guide details

Part b – Intended use and audience

<u>Section 2: Guide Content</u>

Part a – Project planning

Part b – Technical specifications

Part c – Implementation processes

Part d – Supporting tools and software

Part e – Contractual aspects

5.3 Mapping a common Table of Contents

As much as the comparison of the guides to an overall scope was an important process, narrowing down a common table of contents was crucial. Mapping of existing guides helped achieve a table of contents that was relevant to WPI assisting with assembly of a customized guide based on the contents found in these guides.

5.4 Case studies

This section reviews in detail each of the five documents and discusses in detail the common elements found in all of them.

5.4.1 Case 1: Indiana University (IU)

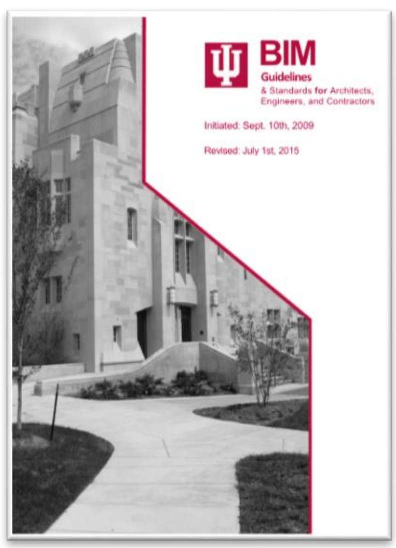


Figure 17: Indiana University BIM Guide

The Indiana University (IU) architect's office first issued IU BIM standards and project delivery guidelines for projects $5 million and over in October 2009. These were later updated in May 2012 for all IU projects.

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

The BIM Guidelines had five major components: Chapter 1 (Requirements) defines software requirements. The deliverable file format for all BIM project models is to be .RVT (Autodesk Revit). Other software, include civil, geo-referenced, and collaboration software must be interoperable with Autodesk Revit.;

Chapter 2 (Process) defines the submission process of two other important documents- *BIM Execution Plan and Integrated Project Delivery (IPD) Methodology Plan*, the chapter also defines and identifies model quality, energy requirements and design deliverable schedule and milestones, from conceptual phase to construction documents;

Chapter 3 (Objectives and Application) defines the detailed BIM requirements for each project phase, from Pre-Design to Commissioning. Each phase has subcategories such as general, energy requirements, deliverables. Along with the BIM requirements, the Guidelines establishes the methods as to how BIM is being transferred from the project beginning to the ending;

Chapter 4 (Ownership and Rights of Data) claimed the ownership of all CAD files, BIM files, and Facility Data belonged to IU;

Chapter 5 (Terminology) is a list of terminologies that would occur during the projects and in the documentations.

5.4.1.1 BIM Execution Plan

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

The BIM Execution Plan shall be submitted to Indiana University by the design team within thirty (30) days of contract award. The BIM Execution Plan is reviewed and approved by Indiana University within fourteen (14) days after the submitting of the BIM Execution Plan (Indiana University Architect's Office 2009). The BIM Execution Plan identified roles and responsibilities of project participant in a BIM environment.

5.4.1.2 IU IPD (Integrated Project Delivery) Methodology Plan

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

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

5.4.1.3 IU BIM Proficiency Matrix

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

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

[THIS SPACE HAS BEEN INTENTIONALLY LEFT BLANK]

Table 2: Comparison of BIM Guides

Categories of Information vs. Implementation Level*	Standards	Contracts (& Technical Specifications)	Business Processes (By Role, etc.)	Tools, Technology, Modelling Guidance
International Framework	☐	☐	☐	☐
National Framework	☐	☐	☐	☐
Owner Organization Guides/ Manuals	☐	☐	☐	☐
Facility Managers/ Operators	☐	☐	☐	☐
Trade-Related/ Associations	☐	☐	☐	☐
Project/ Company- Related Use	☐	☐	☐	☐
Software- Related Use	☐	☐	☐	☐

*Guides are qualified by scope and mapped to this matrix; multiple boxes can be checked

5.4.2 Case 2: Pennsylvania State University

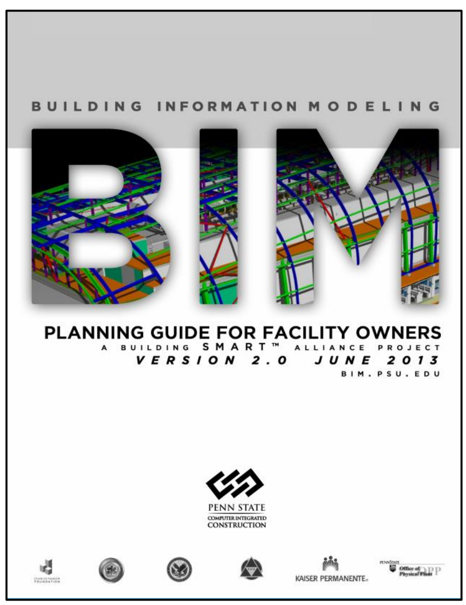


Figure 18: Pennsylvania State University BIM Guide

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

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

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

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

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

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

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

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

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

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

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

[THIS SPACE HAS BEEN INTENTIONALLY LEFT BLANK]

5.4.3 Case 3: Massachusetts Institute of Technology (MIT)

CAD & BIM GUIDELINES

MASSACHUSETTS INSTITUTE OF TECHNOLOGY DEPARTMENT OF FACILITIES 77 MASSACHUSETTS AVENUE CAMBRIDGE, MA 02139-4307

Facility Information Systems
MIT Campus Planning, Engineering, and Construction
April 5th, 2012

v3.2

Figure 19: Massachusetts Institute of Technology BIM Guide

These guidelines at MIT are issued to promote the development of electronic drawings and models suitable for use in the MIT Department of Facilities CAD and BIM environment. Consistency and compatibility with existing MIT documents can only be achieved when these standards are strictly adhered to. Electronic drawings produced and submitted in accordance with these standards have significantly greater value to the Institute. Architects, Engineers, and Contractors delivering documentation to MIT must ensure these standards are reviewed, understood, and followed by those people responsible for preparing electronic drawings and models. An Electronic File Q/A Checklist has been provided to assist in the production of qualified documents.

5.4.3.1 Renovations and space change projects requirements

For typical Renovation and Space Change projects, the Designer is responsible for submitting a complete set of construction documents (CDs) to MIT prior to the beginning of construction. During construction, the Contractors are responsible for submitting complete As-Built documentation to the project team as described in their contracts (typically in both electronic and hardcopy formats) and Designers are responsible for submitting the record documents to MIT based on this As-Built documentation. Construction Documents and Record Documents submitted to MIT need to adhere the criteria outlined in their document.

Designers that are not familiar with MIT's CAD requirements must meet jointly with the MIT Project Manager and representatives from MIT’s Facility Information Systems (FIS) to discuss specific project requirements *prior to the development of any CAD documentation*. Designers should also take this opportunity to relay the project scope to FIS so MIT can furnish Designer with existing drawings that will benefit the design team.

5.4.3.2 Capital project requirement

For typical Capital Projects, the Designer is responsible for submitting a complete set of construction documents (CDs) to MIT prior to the beginning of construction. During construction, the Contractors are responsible for submitting complete As-Built documentation to the project team as described in their contracts (typically in both electronic and hardcopy formats) and Designers are responsible for submitting the record documents to MIT based on this As-Built documentation. Construction Documents and Record Documents submitted to MIT need to meet the criteria outlined in this document. Recognizing the diverse nature of capital projects, Designers need to meet jointly with the MIT Project Manager and representatives of Facility Information Systems (FIS) to discuss specific electronic requirements for the project in the early stages of project startup.

5.4.4 Case 4: Georgia Tech University

Figure 20: Georgia Tech BIM Guide

The intent of the requirements of the guide is to create a prescriptive framework with which BIM enabled teams will coordinate with Georgia Tech, the Board of Regents, the Georgia State Finance & Investment Commission, and other applicable groups. This document will allow all stakeholders to weigh the importance of each requirement on a per-project basis. Through this collaborative effort, a final project-based set of requirements and corresponding BIM Execution Plan will be issued based on what level of BIM proficiency necessary for a given project.

Georgia Tech (GT) requires that all design and construction deliverables for projects be created and derived from building information models, and expects that data associated with the installed components of these facilities be reconciled and validated with the construction deliverables. It is GT's intention to reuse these models and data for facility lifecycle management. Building information models shall be provided throughout the design, construction, and close out phases along with an emphasis on corresponding building data collection to be gathered using the Construction Operations Building Information Exchange (COBie) to capture and record close out data.

COBie is an information exchange used to collect building data in spreadsheets that can be tied to BIMs for efficiency and are used to assign building components unique naming conventions outlined later in the document, so that information can be consumed and validated through GT's data management processes. Unique GUIDs, assigned in the BIM tools, shall be maintained to support data in workflows that can then be used throughout the design, construction, and building handover process.

Portions of this life-cycle oriented data format will be required for a variety of different building information deliverables that will replace paper deliverables. The deliverables for the Close-out in COBie format include, but are not limited to:

• Verification of the design solution against the Program for Design

• Scheduled building equipment/component lists

• Construction submittal register requirements

• Identification of installed equipment and all tagged building products

• Close-out deliverables

5.4.4.1 BIM Execution Plan (BEP)

The BIM Execution Plan is a living document that will continue to mature over the course of project deliverable and milestones. The BEP will be reviewed and approved by GT within fourteen days after the submitting of the BEP for review. The BEP also should include assumed roles and responsibilities of the team even if that party has not yet been identified, such as the construction team.

Design and construction teams will identify for themselves and the persons that within their organizations responsible for managing the BIM(s), or portions of the BIM. Collaborative aspects of the Integrated Project Delivery (IPD) approach are to be harnessed in developing the BEP mentality.

5.4.4.2 Integrated Project Methodology Plan (IPP)

The IPP, integrated within the BEP, should demonstrate a high level of project integration and technological workflows by identifying project methodology and modeling procedures, quality control, and scheduling and model information validation. Examples of IPP's are, but not limited to, Reverse Phase Scheduling and Critical Path Modeling conforming to level of development requirements. Constraints and model role dependencies are described here. Although there is no template for the IPP plan, GT encourages high level planning be incorporated in the BEP.

[THIS SPACE HAS BEEN INTENTIONALLY LEFT BLANK]

5.4.5 Case 5: University of Southern California (USC)

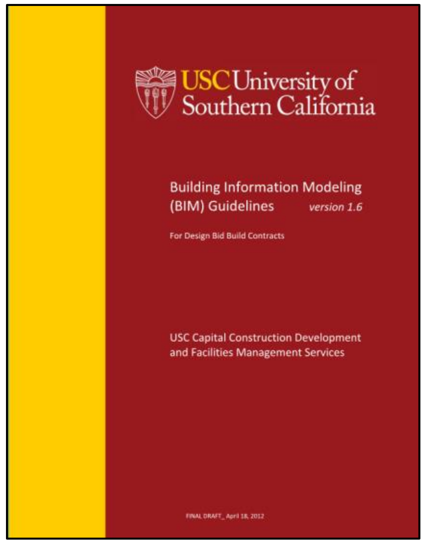


Figure 21: University of Southern California BIM Guide

The document defines the Design and Construction scope of work and deliverables for using Building Information Modeling (BIM) on new USC construction projects, major renovations and other projects as required by USC, based on a Design Bid Build form of Contract.

BIM provides opportunities to vastly improve upon traditional methods of design and construction coordination thereby reducing the potential for costly change orders, providing multiple opportunities for owner review and participation by means of 3D visualization of the project and specialty spaces, and reducing design and construction schedules. In addition, BIM creates opportunities for reusing data for multiple purposes, including the operation and maintenance of USC's facilities. To achieve these ends, the BIM must be structured to achieve the required purposes. The document describes USC's requirements for the production and use of Building Information Models (BIM) in the design, construction, and maintenance of its facilities.

5.4.5.1 BIM Execution plan

As part of their respective proposals/bid submittals, the Architect and the General Contractor must submit a BIM Execution Plan (BEP) describing processes and procedures in place within their organizations used to coordinate and deliver the BIM's and associated data per the guidelines contained herein. USC will evaluate the BEP's and provide feedback to the successful bidder at the time of contract award, after which the Contractor will have 2 weeks to make changes to the BEP and resubmit.

5.5 Conclusion

The five case studies reviewed helped in identifying specific concepts and materials that would be relevant when creating the guide for WPI. Currently, WPI does not have any mandatory guidelines that are required to be complied by the contractors, designers, project managers or any other parties involved with regards to the use of BIM. There are no set rules, regulations, or established requirements that they need to meet when making a submission to WPI during the different stages of the project. The five case studies were reviewed under the same fields and the results are summarized below in Figures 23 and 24.

The five case studies helped identify the common categories of information type like:

- Standards
- Contracts specified (including technical specifications)
- Roles and responsibilities of involved parties
- Tools & technology
- Modeling guidance

University / Focus area	Indianan University (IU)	Pennsylvania State University (PSU)	Massachusetts Institute of technology (MIT)	Georgia tech (GTU)	University of Southern California (USC)
Guide details	- Guidelines and standards for Architects, Engineers, and Contractors. - Required on all construction- new and addition/alteration	Planning guidelines for Facility Owners	CAD and BIM guidelines for department of facilities	- BIM requirements & guidelines for Architects, Engineers, and Contractors.	- BIM guidelines for design bid build contracts - Required for new and renovation projects.
Intended use and audience	- To achieve interoperability between consultants & IU. - Design team, Contractors, Owner (IU)	- Improve construction quality - Reduce RFI's and change orders - Provide facility managers improved facility data at closeout	- Promote development of electronic drawings and models	- To support data in workflows. - For design, construction and building handover process.	- Use of BIM in design, construction and maintenance of facilities
Project Planning	- Identify BIM goals and uses - Design the BIM execution process	- Identify BIM goals and uses - Design the BIM execution process	- Identify BIM goals and uses - Design the BIM execution process	- Identify BIM goals and uses - Design the BIM execution process	- Identify BIM goals and uses - Design the BIM execution process

Figure 22: University BIM guides comparison

[THIS SPACE HAS BEEN INTENTIONALLY LEFT BLANK]

University / Focus area	Indianan University (IU)	Pennsylvania State University (PSU)	Massachusetts Institute of technology (MIT)	Georgia tech (GTU)	University of Southern California (USC)
Implementation processes	- BIM proficiency Matrix - BIM Execution Plan - IPD Methodology Plan	- BIM Implementation team - Roles & responsibilities - BIM Champion - BIM Execution Plan	- BIM Execution Plan	- BIM Execution Plan - Integrated Project Methodology Plan	- BIM Execution Plan
Supporting tools & software	- Autodesk Revit to develop models - Navisworks for reviewing 3D models - ProjectDox for document management & file sharing	- Facility Management Systems (FMS) software packages that include CMMS, CAFM - Autodesk Revit - Adobe PDF	- AutoCAD - Adobe PDF - Autodesk Revit - Autodesk NavisWorks	- AutoCAD - AutoCAD Civil 3D - Autodesk Revit - Autodesk NavisWorks	- Autodesk Revit - Tekla - Autodesk NavisWorks
Deliverables	Models through: - Conceptualization phase - Schematic Design phase - Design Development - Construction documents	- Programming report - Energy model - Design model - Record model - As-built model	Milestone deliverables through: - Design - Construction - Completion For new and renovation, space change projects	- Project close out documents - O&M manuals - COBie requirements	Models through: - Conceptualization phase - Schematic Design phase - Design Development - Construction documents
Contractual Aspects	- Ownership of all CAD files, BIM Models and Facility Data	- Ownership of all CAD files, BIM Models and Facility Data	- Responsibility of designer to submit complete set of CD - Contractor to submit complete set of As-built on project completion	- Ownership of all CAD files, BIM Models and Facility Data	Ownership of all CAD files, BIM Models and Facility Data

Figure 23: University BIM guides comparison

6 WPI-BIM GUILDELINES DOCUMENT STRUCTURE, CONTENTS, AND VALIDATION

The following chapter explores the WPI-BIM Guidelines development approach. The process involved a common framework for BIM guides and identified the information that needed to be integrated into the BIM Model which would be useful for Facilities Management. Having Identified the value of using BIM for Facilities Management the BIM guide was developed for integrating and maintaining this information.

6.1 Research findings

The concept and process of developing the WPI-BIM guide has been illustrated in Figure 24 below. A review of the five university BIM guides helped identify different fields of metadata, map a common table of contents, and utilize keywords that were crucial in the development of the guide. Though the guides were different, a common framework of information helped develop the made-to measure BIM guide for WPI.

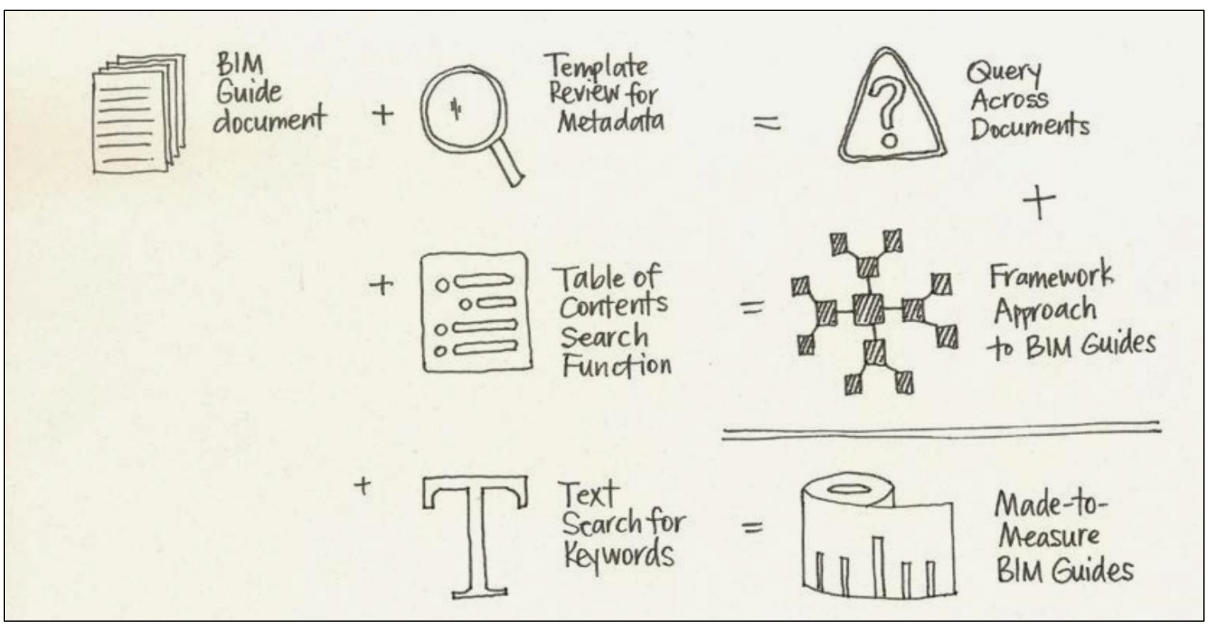


Figure 24: BIM guide project concept

[Source: https://open.library.ubc.ca/cIRcle/collections/52660/items/1.0076411]

A table of contents relevant for the WPI BIM guide was mapped and following chapters were detailed in the BIM guide. The major components of the guide included information on the participating project teams, standards, contract specific information (including technical specifications, roles and responsibilities of involved parties, tools & technology, and modeling guidance.

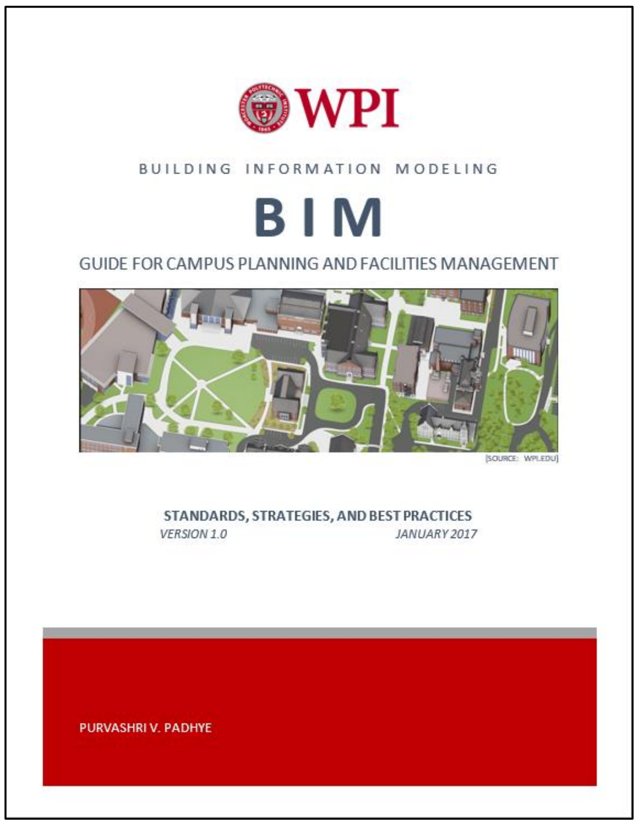


Figure 25: Proposed WPI BIM guide

Chapter 1. Introduction

The first chapter introduces the concept of Building Information Modelling (BIM) and its relevance as the guide addressed the needs of a variety of users regardless of their expertise on the subject. It also talks about the value of BIM has for Facility Owners. The industry-wide adoption of BIM surged from 28% in 2008 to 71% in

2012 with architects, engineers, contractors, and owners engaging with BIM on their projects, and indicating a 75% growth surge over five years (SmartMarket Report, 2012). It highlights how BIM helps with reduction of document errors and emissions, rework, construction cost, project duration, and claims and litigation. It guides the user on the sequential order of procedures and steps necessary to implement BIM and how to successfully use the BIM guide.

Chapter 2. Renovations & Space Change Project Requirements

Since majority projects on campus using this BIM guide will be renovation and retrofit projects, this chapter will guide the users through the various stages of construction and the required deliverables. For example:

- Design phase

  When a project is nearing the end of a design phase, the designer shall submit a complete set of Design documents (DD) in electronic and hard copy format to WPI. The documents should be archived to be used in the future.

- Construction phase

  When a project enters the construction phase, the designer shall submit a complete set of 100% Construction Documents (CD) in electronic and hard copy format to WPI. These documents will be archived as a record of the project.

- Completion phase

  When the project has been completed, it is the responsibility of the contractors to submit a complete set of As-Built (AB) Documents to the project team as mentioned in their contracts.

Chapter 3. New Construction Project Requirements

The next chapter will guide users on how to use the guide through the various stages of construction for a new building on campus. For example:

- Schematic Design phase:

  Design Team may use any method to begin the design process but shall be using a BIM authored model(s) by completion of this phase.

- Design development phase (Detailed Design)

  The Design Team shall continue development of their Building Information Model.

- Construction Document phase

  Continue development of the models created in the Design Development phase.

- Bidding Phase

  Contractors who are bidding the project will follow the guidelines and requirements as set forth by the BIM Execution Plan.

- Construction Phase

  The design team is expected to continuously maintain and update the design intent model(s) with changes made from official construction change directives and as-built mark-ups maintained on site by the contractor(s) during construction.

- Project Close-out

  The design team shall update their respective models with contractor recorded changes (Record Documents), and republish record documents in paper, .DWG and .PDF formats. They would also be required to submit all O&M Manuals.

Chapter 4. CAD Drawing Production

The next chapter provides information on the CAD file production and submittals required for a project. It illustrates on file format standards for WPI. Electronic file format: Construction and record document project drawings must be submitted in the file formats listed below, other formats are not acceptable without the prior consent of WPI's Facility Information Systems (FIS).

- AutoCAD 2008 or higher DWG format only.
- Adobe PDF version 6.0 or higher.
- TIF 6.0

It also provides standards for scales, units, and tolerances. For example: all CAD drawing models shall be drafted at full scale in architectural units, such that one drawing unit equals one inch.

Standards on fonts and text styles help achieve standard AutoCAD fonts, line types, and hatch patterns to avoid content discrepancies in the delivered drawing set.

Another important aspect is the representation of the drawings. A standard template will provide a uniform set of construction documents.

Chapter 5. Revit File Production

The software used to produce the BIM models is Autodesk Revit. All drawings created will be assigned a drawing file name and number. Since we are working on number of buildings on the WPI campus it is most likely to have the same drawing name. This could be confusing while browsing through drawings and thus these have been categorized job wise.

Sheets will be organized in the following sequence:

PC-A-100-Plan views-2015.06.17 which represents the following

Building Name-Discipline Name-Sheet Number-Sheet Description-Date when it was created.

Chapter 6. BIM Deliverables

The first step towards developing the BIM guide would require to draw a BIM Execution Plan that will guide the project and project teams from start to completion.

BIM Execution Plan: Projects using BIM are required to use the **WPI BIM Execution Plan** to document modeling practices. This document declares what is being modeled, the accuracy of the models, the intent of the models, and how project teams work within the models. Software platforms and procedures are also outlined and agreed upon in this document.

The intent of these requirements is to create a prescriptive framework with which BIM enabled teams will coordinate with WPI and other applicable groups. This document will allow all stakeholders to weigh the importance of each requirement on a per-project basis. Through this collaborative effort, a final project-based set of requirements and corresponding BIM Execution Plan will be issued based on what level of BIM proficiency necessary for a given project.

WPI requires that all design and construction deliverables for projects be created and derived from building information models, and expects that data associated with the installed components of these facilities be reconciled and validated with the construction deliverables. It is WPI's intention to reuse these models and data for facility lifecycle management.

Building information models shall be provided throughout the design, construction, and close out phases along with an emphasis on corresponding building data collection to be gathered using the Construction Operations Building Information Exchange (COBie) to capture and record close out data. COBie is an information exchange used to collect building data in spreadsheets that can be tied to BIMs for efficiency and are used to assign building components unique naming conventions outlined later in the document, so that information can be consumed and validated through WPI's data management processes. Unique IDs, assigned in the BIM tools, shall be maintained to support data in workflows that can then be used throughout the design, construction, and building handover process.

Portions of this life-cycle oriented data format will be required for a variety of different building information deliverables that will replace paper deliverables. The deliverables for the Close-out in COBie format include, but are not limited to:

- Verification of the design solution against the Program for Design
- Scheduled building equipment/component lists
- Construction submittal register requirements
- Identification of installed equipment and all tagger building products
- Close-out deliverables

Chapter 7. Archival Print Files and Formats

The idea of maintaining Archival Print Files is to receive a file with complete details to recreate 100% of the information contained in the hard copy original, without creating an excessively large digital file. These files must be in PDF format and they may be produced either directly from CAD/BIM applications or from a scanned hard copy.

Chapter 8. Determine Infrastructure Needs

The WPI FM department must maintain specific infrastructure needs required to support the BIM infrastructure. This includes:

Software (Technical):

- Selecting the hardware/software package
- Compatibility with existing systems
- User friendly

Software (Non-Technical):

- Cost of software
- Choice of a widely used/popular software

Vendor (Technical):

- Technical support
- User training

Software Systems:

- Planning, Design, Construction Software's
- Facility Management Systems

Supporting Hardware Systems:

- Important to support chosen software
- Choice of devices, workspace

Chapter 9. Education and Training

Education:

- Education is critical to helping an organization better understand BIM and the organization’s purpose for using BIM.
- Important to convey what is Building Information Modeling and how can BIM be used. This is important especially for new users.
- Organization’s purpose for including BIM mission statements and the strategic BIM Plan.

Training:

- Identify the subjects to train on.
- Who needs this training?
- What are the different methods to achieve the training?

Chapter 10. Pilot Project Sample

The final chapter gives a detailed example of a completed BIM project on campus for reference. This project has all components of BIM as required by the FM department as the BIM projects stand at this stage on campus.

6.2 Document Validation

After the first version of the WPI-BIM Guidelines document was created, a couple of actions were taken to validate its contributions and to test the workability of the guide. of the proposed approach. This was done in two parts: one by applying all the proposed concepts to a specific model; the second part conducted interviews to collect feedback from the potential users at the Facilities Department.

6.2.1 Proof of concept

The proof of concept consisted in applying the proposed approach to a BIM model of a facility on campus. The facility selected was the Project Center at WPI. The information handed over on this project was a model created by the author and all the attributes required by the FM department were attached to it. The model contained detailed layouts with dimensions of all spaces enclosed. The different attributes attached to the model were the floor finishes, ceiling finishes, 3D representations of the building, space use per

FICM codes, space use with door tags, space utilization and room capacities and MEP utilities and their locations. These drawings were generated and presented on the template finalized by the FM department and the information was stored on the SharePoint website: https://sharepoint.wpi.edu/research/bimfm/documents/ under the student projects tabs. This information was accessible only to authorized personnel's. The use of the SharePoint application on mobile devices made this data easy accessible. The app was free to download and the user could view all pdf files available on SharePoint. The following figures are the documents generated for the Project Center.

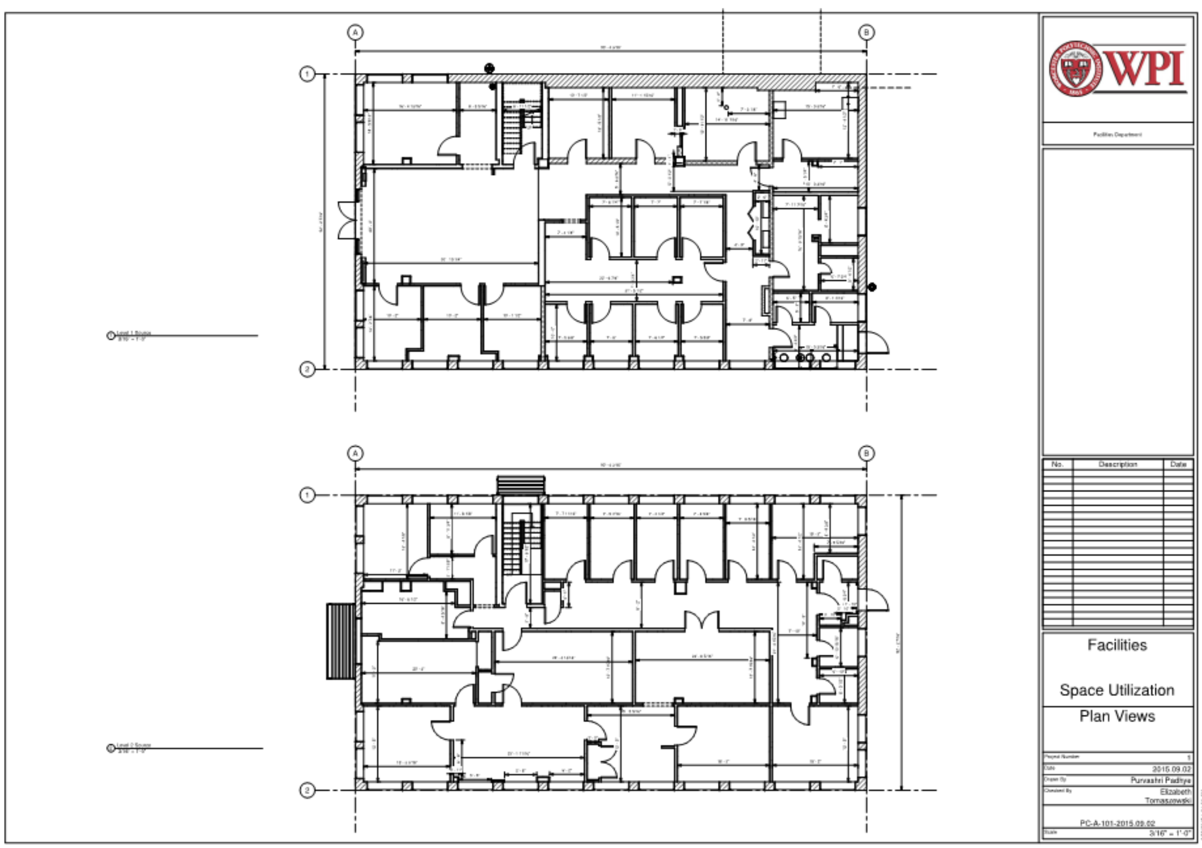


Figure 26: Drawing sheet indicating plans with detailed dimensions

Figure 27: Drawing sheet indicating Floor Finishes

Figure 28: Drawing sheet indicating Ceiling Finishes

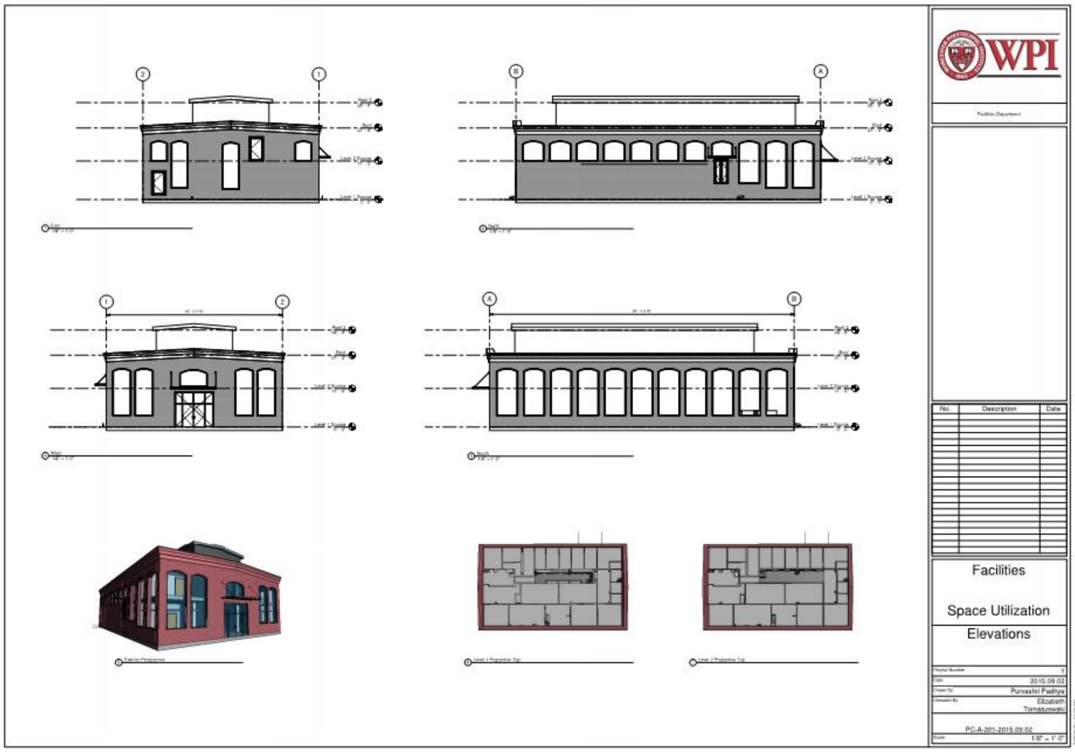


Figure 29: Drawing sheet indicating Architectural detailing

Figure 30: Drawing sheet indicating Space Use per FICM codes

Figure 31: Drawing sheet indicating Space Use (door tags)

Figure 32: Drawing sheet indicating Space Utilization and room capacities.
(Room Space Utilization chart enlarged in Figure 33)

Room Space Utilization							
Level	Department	RCM Classification	Number (door tag)	Name	Area	Capacity	Space Utilization
Level 1 Source	Career Development Centre	310 Office	104	Office	236 SF	1	235.44
Level 1 Source	Career Development Centre	310 Office	105	Office	132 SF	1	132.37
Level 1 Source	Career Development Centre	310 Office	107	Student Worker Office	143 SF	6	23.86
Level 1 Source	Career Development Centre	310 Office	109	Graduate Assistant Office	81 SF	2	40.36
Level 1 Source	Career Development Centre	310 Office	106-F	Office	74 SF	1	73.93
Level 1 Source	Career Development Centre	310 Office	106-G	Office	73 SF	1	73.46
Level 1 Source	Career Development Centre	310 Office	103	Office	129 SF	1	129.13
Level 1 Source	Career Development Centre	310 Office	102	Office	141 SF	1	140.93
Level 1 Source	Career Development Centre	310 Office	101	Office	129 SF	1	128.78
310 Office: 9					1138 SF	15	
Level 1 Source	Career Development Centre	315 Office Service	NA	Copy Room	94 SF	0	
Level 1 Source	Career Development Centre	315 Office Service	108	Kitchen	195 SF	0	
Level 1 Source	Career Development Centre	315 Office Service	106-C	Interview Room	79 SF	1	79.41
Level 1 Source	Career Development Centre	315 Office Service	106-B	Interview Room	79 SF	1	79.31
Level 1 Source	Career Development Centre	315 Office Service	106-A	Interview Room	79 SF	1	78.66
Level 1 Source	Career Development Centre	315 Office Service	106-D	Interview Room	74 SF	1	74.17
Level 1 Source	Career Development Centre	315 Office Service	106-E	Interview Room	74 SF	1	74.31
315 Office Service: 7					674 SF	5	
Level 1 Source	Career Development Centre	780 Unit Storage	109-A	Storage Closet	190 SF	0	
Level 1 Source	Career Development Centre	780 Unit Storage	NA	Storage Closet	38 SF	0	
780 Unit Storage: 2					228 SF	0	
Level 1 Source	Career Development Centre	W05 Lobby	NA	Lobby	627 SF	7	89.64
W05 Lobby: 1					627 SF	7	
Level 1 Source	Career Development Centre	W06 Public Corridor	NA	Corridor	94 SF	0	
Level 1 Source	Career Development Centre	W06 Public Corridor	NA	Corridor	441 SF	0	
Level 1 Source	Career Development Centre	W06 Public Corridor	106	Corridor	279 SF	0	
W06 Public Corridor: 3					814 SF	0	
Level 1 Source	Career Development Centre	W07 Stairway	NA	Stairs	100 SF	0	
W07 Stairway: 1					100 SF	0	
Level 1 Source	Career Development Centre	X03 Public Rest Room	NA	Toilet	189 SF	0	
Level 1 Source	Career Development Centre	X03 Public Rest Room	NA	Toilet	33 SF	0	
X03 Public Rest Room: 2					222 SF	0	
Level 1 Source	Career Development Centre	Y04 Utility/Mechanical Space	113	Utility Closet	42 SF	0	
Level 1 Source	Career Development Centre	Y04 Utility/Mechanical Space	110	Electrical Closet	27 SF	0	
Y04 Utility/Mechanical Space: 2					69 SF	0	
Career Development Centre: 27					3872 SF	27	
Level 1 Source: 27					3872 SF	27	
Level 2 Source	Interdisciplinary and Global Studies Division		212-A	Unknown	12 SF	0	
Level 2 Source	Interdisciplinary and Global Studies Division		NA	Unknown	30 SF	0	
: 2					42 SF	0	
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	NA	Office	150 SF	1	150.12
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	NA	Office	105 SF	1	104.85
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	216	Office	165 SF	1	165.19
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	212	Office	102 SF	1	102.19
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	211-B	Office	104 SF	1	104.14
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	211-A	Office	97 SF	1	97.25
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	210-B	Office	103 SF	1	103.24
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	210-A	Office	103 SF	1	102.89
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	209	Office	168 SF	1	168.25
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	217	Office	225 SF	1	224.57
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	201	Office	205 SF	1	204.81
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	202	Office	307 SF	2	153.39
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	204	Office	218 SF	1	218.02
Level 2 Source	Interdisciplinary and Global Studies Division	310 Office	205	Office	203 SF	1	203.49
310 Office: 14					2256 SF	15	
Level 2 Source	Interdisciplinary and Global Studies Division	315 Office Service	203	Kitchen	189 SF	0	
Level 2 Source	Interdisciplinary and Global Studies Division	315 Office Service	NA	Storage Closet	17 SF	0	
315 Office Service: 2					206 SF	0	
Level 2 Source	Interdisciplinary and Global Studies Division	350 Conference Room	219	Conference Room	308 SF	12	25.66
350 Conference Room: 1					308 SF	12	
Level 2 Source	Interdisciplinary and Global Studies Division	355 Conference Room Service	NA	Storage Closet	13 SF	0	
355 Conference Room Service: 1					13 SF	0	
Level 2 Source	Interdisciplinary and Global Studies Division	780 Unit Storage	NA	Storage Closet	7 SF	0	
780 Unit Storage: 1					7 SF	0	
Level 2 Source	Interdisciplinary and Global Studies Division	W05 Lobby	NA	Lobby	299 SF	2	149.28
W05 Lobby: 1					299 SF	2	
Level 2 Source	Interdisciplinary and Global Studies Division	W06 Public Corridor	NA	Corridor	64 SF	0	
Level 2 Source	Interdisciplinary and Global Studies Division	W06 Public Corridor	NA	Corridor	520 SF	0	
Level 2 Source	Interdisciplinary and Global Studies Division	W06 Public Corridor	Na	Corridor	47 SF	0	
W06 Public Corridor: 3					631 SF	0	
Level 2 Source	Interdisciplinary and Global Studies Division	W07 Stairway	NA	Stairs	123 SF	0	
W07 Stairway: 1					123 SF	0	
Level 2 Source	Interdisciplinary and Global Studies Division	X03 Public Rest Room	NA	Toilet	41 SF	0	
Level 2 Source	Interdisciplinary and Global Studies Division	X03 Public Rest Room	NA	Toilet	47 SF	0	
X03 Public Rest Room: 2					89 SF	0	
Level 2 Source	Interdisciplinary and Global Studies Division	Y04 Utility/Mechanical Space	NA	Electrical Closet	13 SF	0	
Y04 Utility/Mechanical Space: 1					13 SF	0	
Interdisciplinary and Global Studies Division: 29					3986 SF	29	
Level 2 Source: 29					3986 SF	29	
Grand total: 56					7858 SF	56	

Figure 33: Room Space Utilization chart

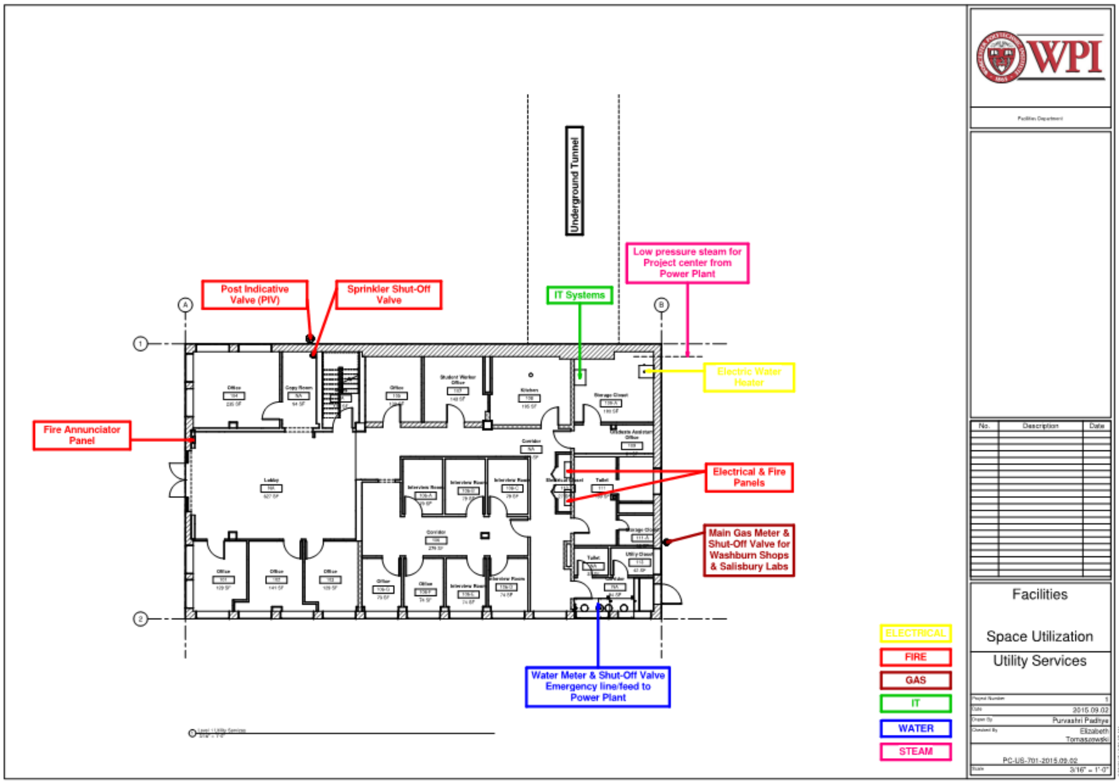


Figure 34: Drawing sheet indicating MEP Utilities and locations

6.2.2 User Feedback

The second part of the validation of the BIM guide and the BIM Project Execution Plan through user feedback is from its users, in this case the WPI Facilities Department. A set of interviews and presentations were conducted with the FM department to validate the concepts proposed in the report. The presentations introduced and elaborated on the concept of the WPI-BIM guide and the process to achieve it.

A questionnaire requesting feedback on the proposed concept and content of the guide clearly identified the expectations and utility for FM. The idea received a positive response and was accepted conceptually. It was agreed that this would act as a document for new and old construction on campus, providing a standard template for BIM implementation. It was important to the users that the data be easily accessible, digitally on their mobile phones and tablets. It should have an easy interface and require minimum training. Another key factor that was identified was that the BIM Guidelines document would require to be updated periodically to be up-to-date and this wouldn't be the last and final version. This, in fact was just a beginning.

Table 3: Interview data tabulation

Participant's	Need for guide	Proposed contents	Missing data	Targeted users of the BIM guide	Expectations from the guide	Relevance for FM department	New/Old construction	Preferred means to access data
Participant 1	Yes	Acceptable	Specifics	- Architects - PM's - Facility managers - Tradesmen	- BIM for campus - Benefits of BIM	- Long term goals	- Both new and old	- Easy interface with minimum training
Participant 2	Yes	Clearly defined		- Architects - PM's - Engineers - Tradesmen	- Easy accessibility - Accurate BIM models	- Useful information	- Both new and old	- Digital access
Participant 3	Yes	Clearly defined	- To develop over time	- Tradesmen - Managers -Contractors	- Consistency - Expand with time - Standard template	- Very relevant	- Both new and old	- Digital access
Participant 4	Yes	Acceptable	-Training for new and existing users - Update the guide	- Facility managers - Trade workers - EH&S managers - Architects - Campus police	- Standard template	- Very relevant	- Both new and old, project specific	- Secure campus network servers
Participant 5	Yes	Clearly defined			- Detailed & comprehensive	- Very relevant	- Both new and old	Incorporate into BMS/BAS data for everyday use
Participant 6	Yes	Clearly defined		- PM's - Engineers - Tradesmen	- Easy accessibility - Easy navigation	- Very relevant	- Both new and old	- Digital access - Desktop application

7 CONCLUSION AND FUTURE WORK

The objective of this research project was to conduct an extensive review of documented approaches and guidelines for BIM uses developed by other universities and incorporate the different experiences with the use of BIM at WPI to create a set of formal guidelines exclusively for WPI for the efficient implementation of BIM in future design, construction, renovation, facility, and space management of a facility.

The BIM guide for the WPI Facilities Department has been created and it is expected to provide a systematic approach for the integration of BIM for existing and new buildings on campus. Strategic planning in the use of BIM will help in assessing existing conditions, align BIM goals and visions, and develop a path for implementation of BIM for operations. The creation of this guide followed a rigorous methodology that included case studies, content analysis and interviews. The case studies conducted provided a wide perspective in the sue of BIM from different organizations of varying sizes and at various BIM implementation levels.

7.1 Benefits of the BIM Guide

The BIM guide for the FM department will benefit in the following ways:

Improved space management: By understanding the details of how space is used, facility professionals can reduce vacancy and ultimately achieve major reductions in real estate expenses. The room and area information in BIM models are the foundation for good space management.

Streamline maintenance: The key challenge in developing a maintenance program is entering the product and asset information required for preventive maintenance. The information about building equipment stored in BIM models can eliminate months of effort to accurately populate maintenance systems.

Efficient use of energy: BIM can also help facilitate the analysis and comparisons of various energy alternatives to help facility managers dramatically reduce environmental impacts and operating costs. By analyzing the costs and the savings of various facility improvements and building system retrofits, facility managers gain a tool to optimize building performance over the life of the building.

Economical retrofits and renovations: A BIM model provides an easier means of representing three-dimensional aspects of the building. Better information about existing conditions reduces the cost and complexity of building renovation and retrofit projects. This provides more accurate and dependable information to contractors, change orders resulting from "surprises" in as-built conditions can be greatly reduced.

Enhanced lifecycle management: Some building design professionals are embedding data on life expectancy and replacement costs in BIM models, thereby helping an owner understand benefits of investing in materials and systems that may cost more initially but have a better payback over the life of the building. The lifecycle data is also very valuable for forecasting ongoing capital improvement costs.

7.2 Recommendations

The validity of the proposed BIM Guide for WPI was established by applying its principles and recommendations in to a pilot project and by collecting feedback from the potential users of this document. An important element in this process is the BIM Project Execution Planning process, in which there have been many concepts identified as recommendations for successful future implementation. If these aspects are taken into consideration, it should lead not only to a better BIM Project Execution Plan, but also a better implementation of BIM throughout the life-cycle of the project. These recommendations are discussed in detail throughout the rest of this section.

- Each project team needs a BIM Execution Plan. A project using the BIM Project Execution Planning Procedure is successful when there is at least one representative with a strong desire to develop the BIM Plan. Typically, from the owner organization or a program/construction management role, these representatives take time to learn the procedure and work to help compile final BIM Plan. They also market the value and necessity of the process to the other project team members. It is important that the representative on a project encourages the team to take the time to plan the work, even if there is strong pressure to begin developing model content.
- Owner involvement is critical throughout the entire process. By providing the guidelines for model and information deliverables, the owner can emphasize the importance of BIM implementation for reaching their desired end goals for the facility. Owner involvement and enthusiasm regarding the process can encourage project team members to seek the best processes that will benefit the entire project. Owners should consider writing a BIM Project Execution Plan into their contract documents to ensure that the document, planning, and project are completed to their expectations.

- It is essential that the project team fosters an open environment of sharing and collaboration. The BIM Execution Planning Process requires organizations to provide information regarding their standard practices, including information files. While certain contract structures can lead to collaboration challenges, the goal of this procedure is to have the team develop a BIM process containing deliverables that will be beneficial to all members involved. To reach this agreement, the project team needs to have open lines of communication. To be successful, the team members must buy-in to the process and be willing to share this intellectual content with other team members.
- The BIM Project Execution Planning Procedure can be adapted for multiple uses and situations beyond the original scope of the project. Even if project teams take only what they need from the procedure and do not complete the entire process, these projects will still create comprehensive BIM Plans. Teams can revise the template documents to fit their specific processes, without modifying any of the core steps of the planning procedure. These teams then can eventually add other portions of the procedure, which will further assist with their planning.
- The BIM Project Execution Procedure can be adapted to different contracting structures. Depending on the contract strategy, additional steps may be needed to ensure project planning success. Developing an organizational BIM Project Execution Plan before project inception can decrease project planning time. By performing organizational level planning, the team can reduce the amount of time spent on each

step of the planning process and maintain a manageable planning scope by defining their standard goals, uses, processes, and information exchanges.

- There is great value in early planning. If planning does not take place early, extra time may be needed to resolve inconsistencies at the later stages of the project. This often results in more time and resources used than the original planning would have needed.
- The BIM Plan should be treated as a live document. When beginning the BIM Project Execution Planning process, it is valuable to understand that the BIM Plan will be constantly changing and updated. It is unrealistic to assume that the project team will have all information necessary to completely develop a BIM Plan at the inception of the project. It will take time to populate the information because additional and new information must be incorporated as project team members are added.
- Once an initial plan is developed, it must be reviewed regularly. A revision schedule needs to set based on a frequency that the project team deems appropriate. Throughout the lifecycle of the project, it is important to keep the initial project goals in mind to ensure that the team is working towards their completion. If there is any deviation, there should be a reassessment of or a reevaluation of the original goals.
- The appropriate resources must be made available to ensure planning success. It is important to keep in mind that the level of effort needed for this process should not be underestimated. Project teams must consider the time allocated for planning when generating both the project schedule and project budget. Due to the learning curve

associated with this process, teams should overestimate the time it will take to produce a BIM Project Execution Plan. The time associated with the learning curve can be reduced by educating involved team members before delving into the process. Without proper planning before the project specific meetings begin, many unexpected issues may arise that could have been solved at an earlier time.

- This procedure creates an opening for all BIM related discussions. Certain issues may have been assumed or not even considered before the initial planning meeting. These discussions, while maybe not pertaining directly to the BIM Execution Plan, may be extremely important and necessary to allow for the entire project to run seamlessly. The BIM Project Execution Planning Process will become more efficient once the teams have gone through the process several times and have developed many of their own planning resources.
- The management and maintenance of a building can be positively affected by storing the closeout documentation within the record BIM, thereby allowing the concepts of Asset Management and Preventative Maintenance to be applied by the Department of Facilities. The key to implementing the exchange of intelligent building information throughout a project requires a contractual agreement by the Owner and Construction Manager. This agreement must specify the components of the building; content required for each element, and the accuracy of the data objects that make up the record BIM.
- The use of BIM in the design and post-construction phases is emerging from a new technology into a developed standard of the industry. Implementing the proposed

BIM guide for the whole lifecycle of the project will be beneficial to the overall success of the project. This guide would need to be updated periodically to stay up to date with the different tool requirements (Revit, AutoCAD, Navisworks). Training users on the guide is very significant for successful implementation of the guide. Another important aspect would be to include BIM in contract document with the designer. Periodically updating and maintaining the BIM guide to have an up-to-date document in hand.

Through this work, owners can reap the benefits of implementing a reliable exchange and storage of information process that not only assists during the design and construction of a facility but also benefits in the long-term, during the lifecycle of the facility, making campus planning and facility management a more efficient process.

Bibliography

American Institute of Architects, 2013, AIA Document G202™–2013, Project Building Information Modeling Protocol Form

Best, R., Langston, C. & De-Valence, G., 2003. Workplace Strategies and Facilities Management, USA: Butterworth Heinemann

BIM Dictionary [online] Available at: https://www.specifiedby.com/resources/bim-dictionary

BIM Terminology [online] Available at: http://www.mitbrand.com/advocacy/bim_language/

Building Information Modeling (BIM): A New Paradigm for Visual Interactive Modeling and Simulation for Construction Projects [online] Available at: http://civil.neduet.edu.pk/ICCIDC-I/Conference%20Proceedings/Papers/045.pdf

BIM Guidelines Inform Facilities Management Databases:
A Case Study over Time, Karen Kensek [online] Available at: http://www.mdpi.com/2075-5309/5/3/899/pdf

BIM Project execution planning guide, 2010 [online] Available at: http://www.engr.psu.edu/ae/cic/bimex/downloads/guide/bim_pxp_guide-v2.0.pdf

BIM Implementation strategies [online] Available at: http://web.stanford.edu/group/narratives/classes/08-09/CEE215/ReferenceLibrary/National%20BIM%20Standard%20(NBIM)/bim_implement_strategies.pdf

BIM Planning guide for facility owners [online] Available at: http://www.fm.virginia.edu/fpc/contractadmin/documents/bimplanningguide.pdf

BIM Planning Guide for Facilities Owners, June 2013 [online] Available at: http://bim.psu.edu/resources/owner/bim_planning_guide_for_facility_owners-version_2.0.pdf

Brian Gilligan and John Kunz Center for Integrated Facility Engineering (CIFE), 2007- VDC Use in 2007: Significant Value, Dramatic Growth, and Apparent Business Opportunity

Clifford F. Hungu, 2013, Utilization of BIM from Early Design Stage to facilitate Efficient FM Operations [online] Available at: http://publications.lib.chalmers.se/records/fulltext/183268/183268.pdf

Doskocil, C., Vaitkunas. M., "Foisie Innovation Studio: The Role of BIM in Lifecycle Collaborative Design", Major Qualifying Project, Worcester Polytechnic Institute, March 2017 (in progress)

East, E.W., 2007. Construction Operations Building Information Exchange (COBIE): Requirements Definition and Pilot Implementation Standard.

Framework & Case Studies Comparing Implementations & Impacts of 3D/4D Modeling Across Projects, Ju Gao & Martin Fischer [online] Available at: http://cife.stanford.edu/sites/default/files/TR172.pdf

Fuller, S. 2010, Life-Cycle Cost Analysis (LCAA), National Institute of Building Sciences [online] Available at: http://www.wbdg.org/resources/lcca.php

Gallaher, M.P. et al., 2004. Cost Analysis of Inadequate Interoperability in the U. S.Capital Facilities Industry

Georgia Tech BIM Requirements & Guidelines for Architects, Engineers and Contractors, 2011 [online] Available at: http://www.facilities.gatech.edu/files/DC/2011_0815_GT_BIM_Requirements_v1.0.pdf

Goedert, J.D. & Meadati, P., 2008. Integrating Construction Process Documentation into Building Information Modeling. journal of Construction Engineering and Management, (July), pp.509–516

Graham Kelly, Michael Serginson, & Steve Lockley, 2013, BIM for facilities management: A review and a case study investigating the value and challenges, [online] Available at: http://www.academia.edu/5144652/BIM_FOR_FACILITY_MANAGEMENT_A_REVIEW_AND_A_CASE_STUDY_INVESTIGATING_THE_VALUE_AND_CHALLENGES

GSA BIM Guide for facility Management [online] Available at: http://www.gsa.gov/largedocs/BIM_Guide_Series_Facility_Management.pdf

Handbook of BIM, Eastman, Teicholz, Sacks & Liston 2011

Indiana University BIM Guidelines & Standards for Architects, Engineers, and Contractors [online] Available at: http://www.indiana.edu/~uao/docs/standards/IU%20BIM%20Guidelines%20and%20Standards.pdf

Karen Kensek, 2015, BIM Guidelines Inform Facilities Management Databases: A Case Study over Time

Lee, G., Sacks, R., and Eastman, C. M. (2006). Specifying parametric building object behavior (BOB) for a building information modeling system. Automation in Construction

Mehmet Yalcinkaya and David Arditi, Building Information Modeling and the Construction Management Body of Knowledge [online] Available at: https://wiki.aalto.fi/download/attachments/80938572/PLM_Conference_MY_Updated_20052013.pdf?version=1&modificationDate=1385329500000&api=v2

NBS International BIM Report 2016 [online] Available at:http://www.bauen-digital.ch/assets/Medienmitteilung/1603-NBS-International-BIM-Report.pdf

Ning Gu and Kerry London, 2010, Understanding and facilitating BIM adoption in the AEC industry [online] Available at: http://www.sciencedirect.com/science/article/pii/S0926580510001317

Ning Gu, Vishal Singh and Xiangyu Wang, 2011, A theoretical framework of a BIM-based multi-disciplinary collaboration platform [online] Available at: http://www.sciencedirect.com/science/article/pii/S0926580510001408

National BIM Standard-United States, 2015 [online] Available at: https://www.nationalbimstandard.org/files/NBIMS-US_FactSheet_2015.pdf

Pavan Meadati, BIM Extension into Later Stages of Project Life Cycle http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.543.2104&rep=rep1&type=pdf

Postsecondary Education Facilities Inventory and Classification Manual (FICM): 2006 Edition [online] Available at: http://nces.ed.gov/pubs2006/2006160.pdf

Sergio O. Alvarez-Romero, 2014, Use of Building Information Modeling technology in the integration of the handover process and facilities management (PhD thesis report, WPI)

SmartMarket Report, 2012 [online] Available at: http://bimforum.org/wp content/uploads/2012/12/MHC-Business-Value-of-BIM-in-North-America-2007-2012-SMR.pdf

Susan Keenliside, 2015, Comparitive analysis of existing building information (BIM) guides [online] Available at: https://open.library.ubc.ca/cIRcle/collections/52660/items/1.0076411

The Uses of BIM-Classifying and Selecting BIM Uses [online] Available at: http://bim.psu.edu/uses/the_uses_of_bim.pdf

The Ohio State University- BIM Project Delivery Standards [online] Available at: https://fod.osu.edu/bim/ohio-state_bim_pds.pdf

Trevor Bertin, Kelsey McMenamy, James Ricci and Peter Schembri, 2011, Enhancing Facilities Management and Structural Design through Building Information Modeling [online] Available at: https://web.wpi.edu/Pubs/E-project/Available/E-project-031511-115720/unrestricted/MQP_Rec_1_Final_Report.pdf

University of Southern California- BIM guidelines [online] Available at: http://facilities.usc.edu/uploads/documents/cas/BIMGuidelines_VS1_6_2012.pdf

Worcester Polytechnic Institute [online] https://www.wpi.edu/about

Worcester Polytechnic Institute Sustainability Tracking, Assessment & Rating System (STARS) Report, 2015 [online] Available at: https://www.sierraclub.org/sites/www.sierraclub.org/files/worcester-polytechnic-institute-ma.pdf

Worcester Polytechnic Institute Acronym Dictionary [online] Available at: http://wpi.collegeacronyms.org/buildings.html

Worcester Polytechnic Institute Standard Eight: Physical Resources [online] Available at: https://web.wpi.edu/Images/CMS/Outcomes/standard08.pdf

Appendix A: Terminology

A

As-Built Documents

As-built documents are the collection of paper drawings or electronic drawings that typically reside in the contractor's onsite trailer that contain mark-ups, annotations, and comments about changes that have been made to the contract documents during the construction phase.

As-Built Model

Design Intent Models that have been updated throughout the construction process. These changes and updates have been communicated from the Contractor to the Design Team through the comments, annotations, and mark-ups from the As-Built Documents. These typically, but not always, are discipline specific models.

B

BIM Execution Plan (BEP)

A plan that is created from the WPI BIM Execution Plan Template that is to be submitted thirty days after contract award. The BEP helps to define roles and responsibilities within a project team.

BIM Proficiency Matrix (BPM)

A matrix designed to measure the expertise of a firm as it relates to using a BIM process on projects. It will be used as one of the many selection criteria during the selection process.

C

COBie - Construction Operations Building Information Exchange

COBie is a standard of information exchange that allows information to be captured during design and construction in a format that can be used during the operations of a building once completed.

Critical Path Modeling

Critical Path Modeling is a method of demonstrating Integrated Project Delivery, and tied to the AIA E202 level of development approach. It sets a plan within the design team that accounts for the activities of each discipline and how they interact with each other. It builds upon a critical path method for those activities, and allows the project team to schedule a complete project.

D

Design Team

The Design Team is considered the Architect and all of the consultants that provide design services for a project. These design services can be rendered at any time during the project.

DWF

DWF is a file type developed by Autodesk to be locked and non-editable file for drawing sheets and model data. It can be used as a file transfer for estimating data, markups, and other third party software. It can be a combination of 3D and 2D information within the same file.

DWG

DWG is a native AutoCAD file format. It is a widely-used file format for exchanging drawing information and 3D information to different programs. While not a database file type, it still has lots of uses for exchanging information.

E

EIM - Energy Information Model

EIM is a concept of producing a “light” and “lean” model that can be used for simulating the building’s performance very early within the design process. The EIM is the process of modeling only the exterior envelope, and the interior volumes to produce a model that energy modeling software can use.

F

FICM - Post Secondary Facilities Inventory and Classification Manual

FICM is standard that describes practices for initiating, conducting, reporting, and maintaining an institutional facilities inventory.

I

IPD - Integrated Project Delivery

IPD describes a contractual relationship between all members of the project team including the Owner, Designers, Consultants, and Construction teams. It is a project delivery method that integrates people, systems, business structure and practices into a process that collaboratively harness the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction.

IPD Methodology

IPD Methodology is a concept that uses methods from the IPD contracts, but does not have the contracts in place. It idealizes the concepts of integration of all team members to try and benefit the entire project.

IPP Methodology Plan

The IPP Methodology Plan is a declaration of how the project team will achieve the goals of an IPP Methodology. The plan can have several components and is encouraged to be part of the BEP. The completion of a Reverse Phase Schedule or Critical Path Modeling is two examples of an IPD Methodology Plan.

L

LEED

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is a suite of standards for environmentally sustainable construction. Based on a point system, a building can achieve different ratings based on the performance of the design, construction, and operation of the building.

N

NavisWorks

NavisWorks is software that allows for the viewing of multiple model formats. This ability to "view" these files also allows NavisWorks to simulate the interaction between model files. That includes interference reporting, time lining, and coordination.

NWC

An .NWC file is a NavisWorks Cache File that is used by NavisWorks to quickly read many other file types. All linked files in NavisWorks have an .NWC file created automatically. In addition, Revit will export directly to the very small file type of .NWC for quick access by NavisWorks.

NWD

A much larger file than the .NWC, the .NWD file shows snapshots in time of a NavisWorks file. No linked files exist but all geometry is included.

NWF

The .NWF file is a native NavisWorks file that has all linked files, interferences/ collisions, markups, animations, schedules, etc.

O

Open Architecture

Open Architecture is a concept of creating a framework that helps to describe a common set of rules for how a project is created. This includes what types of software, the interoperability of the information, and how the participants interact with each other. This is different from open standards in that it promotes progress while not anchoring forward thinkers to a rigid standard.

P

Phases

The phases of a project can be describe in two different ways as the adoption of IPD terminology starts to penetrate the BIM Execution Plan and the IPD Methodology Plan. Below is a list of the traditional names followed by the IPD name.

Pre-Design/Conceptualization Phase

Schematic Design/Criteria Design Phase

Design Development/Detailed Design Phase

Construction Documents/Implementation Phase

Project Team

The Project Team is considered the combination of the Design Team, Contractor, and at times, GT faculty; a complete team needed to make holistic project decisions and approvals.

R

Record Drawing

The production of Record Drawings is the capturing of the As-Built Document's annotation, comments, and mark-ups in a drawing format only. This does not typically include the updating of any models.

Reverse Phase Scheduling

Reverse Phase Scheduling Is a method of demonstrating Integrated Project Delivery. It sets a plan within the design team that accounts for the activities of each discipline and how they interact with each other. It uses the completion date as a point to work backward from to schedule all of the project's activities.

RVT

An .RVT file is a Revit native file type. It is also the deliverable file format for all projects. This includes all of the Design Team's models.

Appendix B: Interview Data

B.1 Questionnaire for Interviews

1. Do we need a Guide?
2. What do you think of the Proposed Content of the presentation?
3. What am I missing?
4. Who would be the users of the BIM guide?
5. What are your expectations from a BIM guide?
6. According to you, how helpful is a BIM guide for FM department?
7. How extensive would you like the BIM execution plan for new construction?
8. How extensive would you like the BIM execution plan for an existing construction?
9. According to you, what BIM deliverables are you expecting for the campus?
10. Pilot projects could be buildings that have already been completed for the FM BIM project.
11. What is your most preferred means to access the BIM data? (Secure data)
12. Who would have access to the final files?
13. Any additional inputs/comments/feedback for the guide?

B.2 Interview Feedback

B.2.1 Participant 1: Bill Spratt

Director of Facilities Operations, Worcester Polytechnic Institute

1. Do we need a Guide?

   - I think a guild would be helpful to make sure our BIM models are consistent building to building

2. What do you think of the Proposed Content of the presentation?

   - So far so good.

3. What am I missing? It is a good general outline. It is missing specifics, but I am assuming that is the next step.

4. Who would be the users of the BIM guide?

   - New project architects, project managers, and facilities operations managers and tradesmen.

5. What are your expectations from a BIM guide?

   - That is sets the stage for how BIM will be defined on campus and also builds a foundation for end users to understand the benefits of BIM and how they can use it to enhance their work.

6. According to you, how helpful is a BIM guide for FM department?

- It is useful as long as it is clear to understand and we have the tools to actually use a BIM system. It can't be something that is done once and sits on a shelf after.

7. How extensive would you like the BIM execution plan for new construction?

   - It should be extensive for new construction. It is a onetime chance to get all the data managed well.

8. How extensive would you like the BIM execution plan for an existing construction?

   - It needs to be as complete as practical. Some older buildings will not have the data needed to make it robust. So, we have to be able to gather as much data as we can without having to dig too deep. All critical items should be on an existing building model like shut offs, major equipment, and an accurate space model.

9. According to you, what BIM deliverables are you expecting for the campus?

   - Accurate space representations of the buildings, all major building components shown, shut off valves, life safety systems, and the ability to modify the space as new projects change the building.

10. Pilot projects could be buildings that have already been completed for the FM BIM project.

    - We do have several buildings started. Piloting building that already have work on them makes sense. Keep in mind we have yet to actually use the system as it is intended. We need to go from theoretical ideas to a practical use.

11. What is your most preferred means to access the BIM data?

- (Secure data) An easy interface that does not take constant training and use to be proficient at.

12. Who would have access to the final files?

- Anyone who is authorized to see them.

B.2.2 Participant 2: James Bedard

Director of Construction Services, Worcester Polytechnic Institute

1. Do we need a Guide?

    - Yes – This material will be very helpful in a wide variety of areas in the Facilities Management Disciplines

2. What do you think of the Proposed Content of the presentation?

    - The presentation was well organized and clearly defined.

3. What am I missing?

    - This is not something that you are missing but a slight correction. The house on Regent Street is #15 not #25.

4. Who would be the users of the BIM guide?

    - Project Managers
    - Architects & Designers
    - Engineers
    - Tradesmen

5. What are your expectations from a BIM guide?

    - An organized easy to access and use set of guidelines on the BIM Models.

6. According to you, how helpful is a BIM guide for FM department?

- This information could be very useful if it is easy to use, current, and accessible by the people that need it.

7. How extensive would you like the BIM execution plan for new construction?

    - This is the opportunity to work with the architects and get the information in the format that we are looking for from the start. We need to make sure that we are engaging you and you teams early in the process to ensure consistency. This is our greatest opportunity to get MEP, structural, site, and all other building systems.

8. How extensive would you like the BIM execution plan for an existing construction?

    - This is the piece that is going to take some time but we should start with the architectural as they can be the used for many applications in and out of Facilities (space planning, lab analysis, ADA, etc.) and then move onto MEP which would be valuable to the trades.

9. According to you, what BIM deliverables are you expecting for the campus?

    - Accurately measure buildings models with consistent formatting.

10. Pilot projects could be buildings that have already been completed for the FM BIM project.

11. What is your most preferred means to access the BIM data?

    - Secure data

12. Who would have access to the final files?

- This is highly accurate and detailed information and distribution should be controlled for security reasons, I would think that Campus Police, Facilities, Space Planning, etc.

B.2.3 Participant 3: Liz Tomaszewski

Facilities Systems Manager, Assoc. Director of Sustainability, Worcester Polytechnic Institute

1. Do we need a Guide?
   - Yes!

2. What do you think of the Proposed Content of the presentation?
   - Very good.

3. What am I missing?
   - This guide will develop over time. Right now we are starting with the basics.

4. Who would be the users of the BIM guide?
   - Tradesmen, managers, contractors

5. What are your expectations from a BIM guide?
   - Consistency of information in a standard format that is accessible to all who need it. Over time, I expect it to grow to include more aspects of building attributes.

6. According to you, how helpful is a BIM guide for FM department?
   - Huge.

7. How extensive would you like the BIM execution plan for new construction?
   - We need to have a standard template that is mandatory for new construction projects.

8. How extensive would you like the BIM execution plan for an existing construction?

    - Extensive, but with room to add over time.

9. According to you, what BIM deliverables are you expecting for the campus?

    - Basically a standard template with all attributes across all buildings. And room to expand.

10. Pilot projects could be buildings that have already been completed for the FM BIM project.

11. What is your most preferred means to access the BIM data?

    - Secure data on a smart device

12. Who would have access to the final files?

    - Specifically designated individuals, including tradesmen, management, and contractors.

13. Any additional inputs/comments/feedback for the guide?

    - Ensure that we can grow the guide with time. Simplicity and accessibility are key. Standard formatting.

B.2.4 Paticipant 4: Nick Palumbo

Project Manager, Department of Facilities, Worcester Polytechnic Institute

1. Do we need a Guide?

    - Yes

2. What do you think of the Proposed Content of the presentation?

    - Satisfactory

3. What am I missing?

    - Guidelines for updating the guide to stay current with future technologies and standards; Training for new users; Re-Training for existing users looking to stay current with the latest technologies and practices. Who will be responsible for keeping the BIM models current?

4. Who would be the users of the BIM guide?

    - Facilities Managers, Trade Workers, Environmental Health and Safety (EH&S) Managers, Outside Vendors (Architects, Consultants, Construction Managers, Subcontractors), Campus Police.

5. What are your expectations from a BIM guide?

6. According to you, how helpful is a BIM guide for FM department?

    - With a large number of users, a standardized set of BIM guidelines will be essential

7. How extensive would you like the BIM execution plan for new construction?

- I think this depends on the specific project in question. Perhaps there could be a baseline template that would be modified to meet the needs of each specific project based on feedback from a representative group on users during the planning phase of the project.

8. How extensive would you like the BIM execution plan for an existing construction?

    - See above.

9. According to you, what BIM deliverables are you expecting for the campus?

    - Searchable database of building information (approved product submittals, as-builts, warranties, functional testing data, Cx reports, training documents and videos, maintenance info); The same information also embedded in the visual 3D models; Accurate coordinated 3D Models with exposed and in-wall MEP routing, valve tags, cleanouts, detailed building construction. Progress photos. Software and information available on handheld devices (iPads and iPhones).

10. Pilot projects could be buildings that have already been completed for the FM BIM project.

11. What is your most preferred means to access the BIM data?

    - Secure data directly from the secure campus network servers.

12. Who would have access to the final files?

    - See #4.

B.2.5 Participant 5: Roger Griffin

Associate Director for MEP, Worcester Polytechnic Institute

1. Do we need a Guide?

   - Yes I believe there needs to be a guide mostly to provide the most useful content and reduce miscellaneous or redundant information.

2. What do you think of the Proposed Content of the presentation?

   - Excellent work.

3. What am I missing?

   - Nothing at this time, based on the fact that most of our buildings are older and haven't been developed with BIM, it will take time to build.

4. Who would be the users of the BIM guide?

   - Work order processing or Capital Improvments.

5. What are your expectations from a BIM guide?

   - That we could start with one group of information at a time, for example "Plumbing fixtures" and then go through the whole campus with that item.

6. According to you, how helpful is a BIM guide for FM department?

   - It would be very helpful.

7. How extensive would you like the BIM execution plan for new construction?

   - Fully extensive, basically everything to start with.

8. How extensive would you like the BIM execution plan for an existing construction?

    - As I listed above, start with MEP specific items, valves, electrical power panel locations, etc.

9. According to you, what BIM deliverables are you expecting for the campus?

    - Answer 8.

10. Pilot projects could be buildings that have already been completed for the FM BIM project.

    - Yes, that would be excellent for guide development as well.

11. What is your most preferred means to access the BIM data?

    - (Secure data) Incorporate into the BMS/BAS data fields which we use every day, this way we would always have information available.

12. Who would have access to the final files?

    - As Needed.

13. Any additional inputs/comments/feedback for the guide?

    - It looks like you are on the right track, thank you.

B.2.6 Participant 6: Theresa Mailloux

Facilities Operations Coordinator, Worcester Polytechnic Institute

1. Do we need a Guide?

   - Yes.

2. What do you think of the Proposed Content of the presentation?

   - Great start.

3. What am I missing?

   - I think with a 'work in progress' we may not know this answer until we are looking for it.

4. Who would be the users of the BIM guide?

   - Trades, Customer service, Project manager.

5. What are your expectations from a BIM guide?

   - Must be easy to use and navigate, must be quick to pull up and show information requested.

6. According to you, how helpful is a BIM guide for FM department?

   - Could be very valuable in day to day operations.

7. How extensive would you like the BIM execution plan for new construction?

   - As simple and broad as possible.

8. How extensive would you like the BIM execution plan for an existing construction?

- As simple and broad as possible.

9. According to you, what BIM deliverables are you expecting for the campus?

    - Sustainability, building layout, emergency exits

10. Pilot projects could be buildings that have already been completed for the FM BIM project.

11. What is your most preferred means to access the BIM data? (Secure data)

    - Desktop application, app for cell phone.

12. Who would have access to the final files?

    - All facilities trades, managers, customer service.

13. Any additional inputs/comments/feedback for the guide?

    - Needs to be very simple and user friendly. Information has to be accurate not similar. Who will be responsible for updating information?

      How easy will it be to make updates.

Appendix C: Worcester Polytechnic Institute BIM Guide

[THIS SPACE HAS BEEN INTENTIONALLY LEFT BLANK]

BUILDING INFORMATION MODELING

B I M

GUIDE FOR CAMPUS PLANNING AND FACILITIES MANAGEMENT

[SOURCE: WPI.EDU]

STANDARDS, STRATEGIES, AND BEST PRACTICES

VERSION 1.0 *JANUARY 2017*

PURVASHRI V. PADHYE

Executive Summary

The Building Information Modelling guide (BIM) is developed to support project teams by leading them through a systematic process for BIM. The Architectural, Engineering, Construction, and Operations (AECO) industry emphasizes the need for facility owners to implement BIM throughout the lifecycle of the facility so that information can be derived during a project that will add value to the business operations. Therefore, this BIM guide is developed to assist facility owners to develop strategies, implementation, and procurement plans for integrating BIM in the organization.

The BIM guide focuses on streamlining the planning and implementation of BIM within a facility or project. The tools and processes can be project specific and can vary with a focus on facility operations after complete.

This Guide presents a structured approach to effectively plan the integration of BIM within WPI. Three planning procedures are presented:

- STRATEGIC PLANNING: To assess existing conditions on campus, align BIM goals and objectives with desired BIM uses and develop a transition plan for BIM implementation.
- IMPLEMENTATION PLANNING: To develop the detailed implementation plan within the operations of the organization.
- PROCUREMENT PLANNING to identify key issues to consider when creating BIM project requirements.

Advisory Members

GUILLERMO F. SALAZAR, Associate Professor, Civil & Environmental Engineering

ALFREDO DIMAURO, Assistant Vice President of Facilities

BILL SPRATT, Director of Facilities Operations

ROGER GRIFFIN, Associate Director for MEP

BILL GRUDZINSKI, Chief Engineer

THERESA MAILLOUX, Facilities Operations Coordinator

TERRENCE PELLERIN, Associate Director of Buildings and Events

JIM BEDARD, Director of Construction Services

NICK PALUMBO, Project Manager

DANIEL SARACHICK, Director of Environmental Health and Safety

LIZ TOMASZEWSKI, Facilities Systems Manager, Associate Director of Sustainability

Acknowledgements

I would like to express my deepest appreciation to all those who encouraged me and helped me complete this BIM guide.

A special gratitude to my supervisor, Professor Guillermo Salazar whose guidance, contribution and encouragement helped me to coordinate and successfully complete the following guide.

I would like to acknowledge with much appreciation the crucial role of Liz Tomaszewski, for her stimulating support and suggestions which helped to form the basis for this research.

I want to thank everyone at the Facilities Department for their valuable inputs and time to help formulate the research, especially Jim Bedard, Alfred Di Mauro, Bill Spratt, Roger Griffin, Theresa Mailloux and Nick Palumbo.

A big thank you to Hannah Poirier for helping with coordinating, organizing meetings and presentations with the Facilities Management department.

I would like to express my gratitude towards my parents and members of my family for their support and encouragement towards the completion of this guide.

Table of Contents

Executive Summary 1

Advisory Members 2

1 INTRODUCTION 7

1.1 What is Building Information Modelling (BIM)? 7

1.2 The value of BIM for Facility Owners 7

1.3 How to Use this Guide 8

2 RENOVATIONS AND SPACE CHANGE PROJECTS REQUIREMENTS 10

2.1 Deliverables for Renovations and space change projects 10

2.1.1 Design phase 10

2.1.2 Construction phase 10

2.1.3 Completion phase 11

3 NEW CONSTRCUTION PROJECTS REQUIREMENTS 12

3.1 Schematic design phase 13

3.1.1 Model contents 13

3.1.2 Level of Detail 14

3.1.3 Design program and space validation 14

3.1.3 Design data documentation 14

3.1.4 Initial conflict report and clash detection 15

3.2 Design development phase 15

3.2.1 Architectural 15

3.3 Construction documents phase 17

3.4 Bidding phase 17

3.5 Construction phase 18

3.6 Project Closeout phase 18

3.6.1 Design team as-builts 18

3.6.2 Contractors record documents 19

3.6.3 Operations and Maintenance (O&M) manuals 19

4 CAD DRAWING PRODUCTION 21

4.1 File format at setup 21

4.1.1 Electronic file format ... 21
4.1.2 Scales, Units, and Tolerances ... 21
4.1.3 Fonts and Text Styles ... 21
4.2 Title Blocks ... 22
4.2.1 Required Title Block Information ... 22
4.2.2 Required Sheet Information ... 22
5 REVIT FILE PRODUCTION ... 24
5.1 File format at setup ... 24
5.1.1 Required Drawing Information ... 24
5.2 Translating CAD files to DWG format ... 26
5.2.1 Translating from other CAD software ... 26
5.2.2 Translating from BIM software ... 26
5.2.3 DWG File Translation Testing ... 26
6 BIM DELIVERABLES ... 27
6.1 BIM Execution Plan ... 27
6.2 Model information and level of details: ... 28
6.2.1 Architectural detailing ... 28
6.3 BIM Models and Deliverables ... 30
6.3.1 Use of Revit and NavisWorks ... 30
7 ARCHIVAL PRINT FILES AND FORMATS ... 31
7.1 PDF File Creation ... 31
8 INFRASTRUCTURE NEEDS ... 32
9 EDUCATION AND TRAINING ... 34
9.1 Education ... 34
9.2 Training ... 34
10 PILOT PROJECT SAMPLE ... 36
10.1 Project 1: Project Center ... 36
Bibliography ... 43
Terminology ... 44

List of Figures

Figure 1: Deliverable and Milestone schedule 12
Figure 2: Project Center: Drawing sheet indicating Floor Finishes 36
Figure 3: Project Center: Drawing sheet indicating Ceiling Finishes 37
Figure 4: Project Center: Drawing sheet indicating Architectural detailing 38
Figure 5: Project Center: Drawing sheet indicating Space Use per FICM codes 39
Figure 6: Project Center: Drawing sheet indicating Space Use (door tags) 40
Figure 7: Project Center: Drawing sheet indicating Space Utilization and room capacities 41
Figure 8: Project Center: Drawing sheet indicating MEP Utilities and locations 42

1 INTRODUCTION

This section of the guide provides an overview of Building Information Modelling (BIM) along with other important aspects of BIM that will assist with the usage of the guide.

1.1 What is Building Information Modelling (BIM)?

The U.S. National Building Information Modeling Standard (NBIMS-US) states that Building Information Modeling (BIM) "is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward."

It is a process of creating an electronic model of a facility for visualization, engineering analysis, conflict analysis, code criteria checking, cost engineering, as-built product, budgeting, and many other purposes. The model serves as a knowledge rich resource for all project participants that helps in information management and a collaborative process.

1.2 The value of BIM for Facility Owners

Implementation of BIM is gaining momentum within the Architectural, Engineering, Construction, and Operations (AECO) Industry. Project teams are now moving from standard 2D to 3D models that can be easily modified, Maintained, and coordinated throughout the lifecycle of a facility.

The 2012 BIM Smart Market Report states that the industry-wide adoption of BIM surged from 28% in 2008 to 71% in 2012 with architects, engineers, contractors, and owners engaging with BIM on their projects, and indicating a 75% growth surge over five years. BIM helped with reduction of document errors and emissions, rework, construction cost, project duration, and claims and litigation.

In 2007, Stanford University's Center for Integrated Facilities Engineering (CIFE) showed that BIM provided a 40% reduction of unbudgeted changes; provided cost estimates within 3% of the traditional estimates; contract savings of up to 10% with the use of clash detection; and reduced project time by up to 7%. These figures may vary but the benefits of BIM continue to grow with owners recognizing the value of BIM and its benefits to the organization.

1.3 How to Use this Guide

This guide is for facility owners who operate and maintain facilities at WPI and is a resource to integrate BIM in the operational processes based on the organization's current level of BIM implementation/maturity. It provides the sequential order of procedures and steps necessary to implement BIM.

These guidelines will help promote the development of electronic drawings and models suitable for use in the WPI Facilities Department. The consistency and compatibility required with existing WPI documents can be achieved when these standards are implemented within the organization. Working through different projects, electronic drawings produced and submitted in accordance with these standards will have greater value to the organization. Architects, Engineers, and Contractors delivering documentation to WPI must ensure these standards are reviewed, understood, and followed by those people responsible for preparing electronic drawings and models.

The following sections contain essential criteria for developing electronic drawings and models for the use in the WPI CAD and BIM environment.

2 RENOVATIONS AND SPACE CHANGE PROJECTS REQUIREMENTS

When an existing building at WPI is undergoing a renovation or space change project, it is the responsibility of the designer to submit a complete set of construction documents (CDs) to WPI prior to the beginning of construction. During construction, it is the responsibility of the contractors to submit complete As-Built documentation to the project team as described in their contracts (typically in both electronic and hardcopy formats) The designers are responsible for submitting the record documents to WPI based on the As-Built documentation. Construction Documents and Record Documents submitted to WPI will need to adhere to the criteria outlined in this document.

2.1 Deliverables for Renovations and space change projects

The following documentation shall be submitted to WPI at different stages through the project.

2.1.1 Design phase

When a project is nearing the end of a design phase, the designer shall submit a complete set of Design documents (DD) in electronic and hard copy format to WPI. The documents should be archived to be used in the future.

2.1.2 Construction phase

When a project enters the construction phase, the designer shall submit a complete set of 100% Construction Documents (CD) in electronic and hard copy format to WPI. These documents will be archived as a record of the project.

2.1.3 Completion phase

When the project has been completed, it is the responsibility of the contractors to submit a complete set of As-Built (AB) Documents to the project team as mentioned in their contracts (typically in electronic and hardcopy formats). Designers are required to submit the Record Drawings based on the As-Builts and need to comply by the format requirements outlined in this document. Any other additional information if submitted must meet the requirements outlined in WPI Project Archiving Guidelines.

3 NEW CONSTRCUTION PROJECTS REQUIREMENTS

Milestone	Deliverables
Contract Award	Final BIM Execution Plan
Schematic Design Phase	Architectural Model Civil Model COBie Design Data • Contact • Facility • Floor • Space • Zone
Design Development	Architectural Model Civil Model Structural Model COBie Design Data • Contact • Facility • Floor • Space • Type • Component
Construction Documents	Architectural Model Civil Model Structural Model COBie Design Data • Contact • Facility • Floor • Space • Zone • Type • Component • System • Document • Attribute
Close-out	As-built Architectural Model As-built Civil Model As-built Structural Model Operations and Maintenance Manuals Warranties Training programs COBie Design Data • Contact • Facility • Floor • Space • Zone • Type • Component • System • Document • Attribute

Figure 1: Deliverable and Milestone schedule

3.1 Schematic design phase

The Design Team may use any method to begin the design process but shall be using a B IM authored model(s) by completion of this phase. All information needed to describe t he schematic design shall be included in and derived from these models. Deliverables ar e required as stated in the deliverable and milestones schedule in figure 1 .

3.1.1 Model contents

Civil Surface and Utilities

Detailed requirements of what is to be included in surveying deliverables is managed by WPI staff in consultation with the Design Team on a project by project basis. Surveys shall be provided in electronic format and include 3D topographic information indicating paving, retaining walls and civil utilities. The civil engineer will provide control points to use as a reference to develop project gridlines and location. The design team shall model all existing conditions and include the level of information as determined by the project needs. The BIM Execution Plan (BEP) will define the scope and details of the model.

Architectural

The model geometry shall include:

- The building footprint definition and all exterior walls.
- All interior wall definitions with all rooms modeled individually.
- All fenestrations.
- All doors.

- All overhangs, sun shades and roof elements.
- All floors, with a separate floor finish model element per room.

3.1.2 Level of Detail

All elements shall be modeled to the standards set forth by the BEP. Clearances and access zones should be modeled on separate layers. The model should include area, height, volume, location, and orientation.

3.1.3 Design program and space validation

The design team shall use the BIM authoring software and other analysis tools to compare and validate the program requirements with the actual design solution

The following shall be developed automatically from the Building Information Model:

a. Assignable areas and Non-assignable areas measured to inside face of wall objects and designated boundaries of areas.

b. Gross Area measured to the outside face of wall objects.

3.1.3 Design data documentation

The design team shall submit all the design data to WPI in an Excel spread sheet format or a spreadsheet format in compliance with the most current version of COBie. The choice for either would be project specific.

3.1.4 Initial conflict report and clash detection

The design team BIM facilitator should integrate all the models into a single consolidated model and run a clash detection test for this phase of the project. The facilitator could also perform a walkthrough of the model from various perspectives and cross sections to detect any constructability issues. The issues should be addressed on a floor by floor basis. The intention is to have an error and collision free model at the earliest phases of construction.

3.2 Design development phase

3.2.1 Architectural

The design team is required to model the architectural elements to a level that defines the design intent and accurately represents the design solution.

The detail and responsibility to fulfill these modeling requirements should be addressed fully wi thin the BIM Execution Plan.

Architectural Site Plan (also see Civil Engineering section below). Paving, grades, sidewalks, cur bs, gutters, site amenities and other elements typically included on enlarged scale site drawings in vicinity of building.

- Existing conditions to the extent required.
- New interior and exterior walls to their correct and accurate height including but not lim ited to: Doors, windows, openings
- All finishes need to be included within the wall type regardless of the thickness of the

finish.

- Interior and exterior soffits, overhangs, sun control elements
- Parapets, screening elements
- Architectural precast
- Floor, ceiling, and roof systems including but not limited to:
- Appropriate structural items listed below if not provided by the Structural Engineer and integrated into the architectural model for coordination and document generation. Insulation, ceiling systems, and floor are to be included.
- Roof, floor, and ceiling slopes, if needed, shall be modeled.
- Soffits, openings, and accessories shall also be modeled.
- Elevators, stairs, ramps including railing systems.
- Casework, shelving, and other interior architectural elements.
- Furnishings, fixtures, and equipment if not provided by others and integrated into the ar chitectural model for coordination and document generation.
- Furniture (Fixed and Loose).
- Furniture Systems.
- Specialty equipment (food service, medical, etc.).
- Model mechanical, electrical, and plumbing items that require architectural space (toilet s/sinks/etc),
- require color/finish selection (louvers, diffusers, etc.) or affect 3D visualization (lighting f ixtures)

- unless provided by Engineers.
- Clearance zones for access, door swings, service space requirements, gauge reading, and other
- operational clearance must be modeled as part of all equipment and checked for conflicts with other
- elements. These clearance zones should be modeled as translucent solids on a separate layer.

3.3 Construction documents phase

The Design Team should continue development of the models created in the Preliminary Design Phase. Maintain links within the respective models to enable automatic generation of all plans, sections, elevations, custom details, schedules, and data export/ import, analysis as well as 3D views. All information needed to describe the construction documents shall be graphically or alphanumerically included in and derived from these models only. Specifications are not required to be linked within the models, but will be accepted if coordinated.

3.4 Bidding phase

The Design Team shall update the models with all addendum, accepted alternates and/or value enhancement proposals. Contractors who are bidding on WPI projects are required to review the BIM Execution Plan and WPI Building Information Modeling (BIM) Guidelines. Contractor will follow the guidelines and requirements as set forth by the BIM

Execution Plan. Thirty days after the project is awarded for construction, the Design Team shall submit to the University Office one set of the Construction Document Deliverables. This deliverable shall consist of CAD files representing every sheet in the Bid Documents.

3.5 Construction phase

The Design Team is expected to continuously maintain and update the design intent model(s) with changes made from official Construction Change Directives and as-built mark-ups maintained on site by the Contractor(s) during construction site.

Milestone Deliverables in the construction phase (contractor)

- BEP Review
- Discipline Specific Coordination Models
- Clash Detection
- Shop Drawing Models
- Fabrication Models
- As-Built Markups (2D/3D DWF and DWG formats)
- Scheduling and Phasing Models

3.6 Project Closeout phase

3.6.1 Design team as-builts

The Design Team shall ensure that their models are updated per the contractor recorded changes (Record Documents). Republish record documents in paper and .PDF formats. They will also have to submit full model(s) with all needed objects and reference drawings, in required deliverable formats. The design team shall update their respective models with contractor-recorded changes. DWG files shall be provided for all drawing sheets in addition to DWG (bind all xrefs) for the BIM models. All BIM files shall be provided in RVT and NWD.

3.6.2 Contractors record documents

The contractor shall submit one set of scanned field set drawings (Record Documents) in .PDF and .DWG format due 30 days after substantial completion. DWG files shall be provided for all drawing sheets in addition to DWG (bind all xrefs) for the BIM models. All BIM files shall be provided in RVT and NWD. All fields are to be filled out for all documents (sheets) and shall be provided at Close-out.

3.6.3 Operations and Maintenance (O&M) manuals

The contractor shall submit the following information to WPI - two paper copies in binders and a single PDF of the O&M Manuals along with the Construction Operations Building Information Exchange (COBie) current format:

- The make, model, and serial number of each piece of installed equipment
- The location of any equipment installed in the building
- Manufacturer's documents including cut sheets, installation instructions, and recommend maintenance tasks, testing or other reports.

An electronic format of the O&M manuals shall be submitted along with the paper copies, the format shall be color PDF and native Excel (.XLS) files. This will be due 30 days after substantial completion. O&M manual documents should be independently linked to components and systems within the COBie deliverable.

4 CAD DRAWING PRODUCTION

The following section will give information on the drawings produced using CAD and standard for submission of the drawings.

4.1 File format at setup

4.1.1 Electronic file format

Construction and Record Document project drawings must be submitted in the file formats listed below, other formats are not acceptable without the prior consent of WPI's Facility Information Systems (FIS).

- AutoCAD 2008 or higher – DWG format only.
- Adobe PDF version 6.0 or higher.
- TIF 6.0

4.1.2 Scales, Units, and Tolerances

All CAD drawing models shall be drafted at full scale in architectural units, such that one drawing unit equals one inch.

4.1.3 Fonts and Text Styles

Drawings created using non-standard AutoCAD fonts, line types, and hatch patterns can result in content discrepancies in the delivered drawing set. To ensure the integrity of the drawing set and minimize potential problems:

- Only native AutoCAD fonts, line types and hatch patterns are to be used. These are standard support features installed as part of a standard AutoCAD installation.

- Custom fonts, line types and hatch patterns, including those provided by 3rd party software, shall not be used.
- Only these TrueType fonts shall be used: Arial, Courier New, Times New Roman.

4.2 Title Blocks

Each CAD file submitted to WPI shall have only one title block. In paper space, the title block shall be placed with its lower left hand corner point inserted at a coordinate location of (0,0,0). Depending on the purpose of the drawing or facility documentation, the drawing's title block shall contain certain essential information that WPI needs to store and retrieve each drawing in its library.

4.2.1 Required Title Block Information

- Original issue date - this date should not change once the drawing has been issued
- Sheet number
- Title - description of drawing and location information. Location information should include all building, floor, and room numbers as applicable.
- Revision history - as applicable
- Drawing phase - drawings submitted as As-Builts should clearly be marked
- WPI Project number - if applicable
- A/E/C – Consultant responsible for producing the drawings should be clearly identified

4.2.2 Required Sheet Information

- Drawing title - indicating the drawing content, e.g. floor plan, section, detail, etc.

- Sheet identification – must follow the Sheet Naming Convention
- Date of drawing - date of final revision of the record drawing
- Drawing Scale - representing the intended plot scale of the drawing with title block
- North Arrow showing orientation of drawing (when applicable)

5 REVIT FILE PRODUCTION

5.1 File format at setup

All drawings created will be assigned a drawing file name and number. Since we are working on number of buildings on the WPI campus it is most likely to have the same drawing name. This could be confusing while browsing through drawings and thus these have been categorized job wise.

Sheets will be organized in the following sequence:

PC-A-100-Plan views-2015.06.17 which represents the following

Building Name-Discipline name-Sheet number-Sheet description-Date when it was created

5.1.1 Required Drawing Information

In the drawing number, building name will be indicated first to immediately point out which project are we referring to followed by the discipline name followed by the drawing number, the description, and the date it was created on.

Sheets will be numbered consecutively within a series from 00 to 99.

Sheets in a bound set should be organized in the following sequence:

A – Architectural

AL – Architectural Large scale

AD - Architectural Details

D - Rooms by department

I – Interiors

US – Utility Services

FICM - Facilities Inventory and Classification Manual

SU – Space Utilization

Drawing numbering sequence is as follows:

100 series: Architectural plans, Floor finishes layout, Ceiling finishes layout

200 series: Elevations and sections of the building

300 series: Large scale plans, elevations, sections

400 series: Details

500 series: Rooms by department

600 series: Interior area, detailing and door tags

700 series: Utility Services- Mechanical, Electrical and Plumbing indicated

800 series: Space use FICM

900 series: Space Utilization room capacity

The work completed on existing five buildings would be indicated as follows:

PC – Project center

WB – Washburn shops

SL – Salisbury Labs

IH – Institute Halls

RH – Riley Halls

5.2 Translating CAD files to DWG format

5.2.1 Translating from other CAD software

WPI understands that many of its vendors do not use the same version of design software to produce plans for their projects. However, WPI requires that service providers who work with other file formats submit DWG formatted CAD files upon project closeout that are fully compliant with all the standards outlined herein, and which have no significant loss of drawing entities or project data that can result from standard CAD file translation procedures.

5.2.2 Translating from BIM software

Projects using Building Information Modeling (BIM) software like Revit are still required to produce DWG and PDF formats for the projects. The use of the National CAD Standard will help facilitate the production of properly formed DWG files.

5.2.3 DWG File Translation Testing

For firms translating their native CAD file format into DWG format concerned about delivering error-free CAD files to WPI upon project closeout, it is strongly recommended that thorough file translation testing be conducted before the drawing development phase of the project. This will assure early detection of file conversion issues, if any, and allow for corrective measures to be taken before the project closeout period.

6 BIM DELIVERABLES

6.1 BIM Execution Plan

Projects using BIM are required to use the **WPI BIM Execution Plan** to document modeling practices. This document declares what is being modeled, the accuracy of the models, the intent of the models, and how project teams work within the models. Software platforms and procedures are also outlined and agreed upon in this document.

The intent of these requirements is to create a prescriptive framework with which BIM enabled teams will coordinate with WPI and other applicable groups. This document will allow all stakeholders to weigh the importance of each requirement on a per-project basis. Through this collaborative effort, a final project-based set of requirements and corresponding BIM Execution Plan will be issued based on what level of BIM proficiency necessary for a given project.

WPI requires that all design and construction deliverables for projects be created and derived from building information models, and expects that data associated with the installed components of these facilities be reconciled and validated with the construction deliverables. It is WPI's intention to reuse these models and data for facility lifecycle management.

Building information models shall be provided throughout the design, construction, and close out phases along with an emphasis on corresponding building data collection to be gathered using the Construction Operations Building Information Exchange (COBie) to capture and record close out data. COBie is an information exchange used to collect building data in spreadsheets that can be tied to BIMs for efficiency and are used to assign building components unique naming conventions outlined later in the document, so that information can be consumed and validated through WPI's data management processes. Unique IDs, assigned in the BIM tools, shall be maintained to support data in workflows that can then be used throughout the design, construction, and building handover process.

Portions of this life-cycle oriented data format will be required for a variety of different building information deliverables that will replace paper deliverables. The deliverables for the Close-out in COBie format include, but are not limited to:

- Verification of the design solution against the Program for Design
- Scheduled building equipment/component lists
- Construction submittal register requirements
- Identification of installed equipment and all tagger building products
- Close-out deliverables

6.2 Model information and level of details:

6.2.1 Architectural detailing

Model the architectural elements to a level that defines the design intent and accurately represents the design solution. The detail and responsibility to fulfill these modeling requirements should be addressed fully within the BIM Execution Plan.

- Architectural Site Plan (also see Civil Engineering section below). Paving, grades, sidewalks, curbs, gutters, site amenities and other elements typically included on enlarged scale site drawings in vicinity of building.
- Existing conditions to the extent required.
- New interior and exterior walls to their correct and accurate height including but not limited to: Doors, windows, openings

All finishes need to be included within the wall type regardless of the thickness of the finish

Interior and exterior soffits, overhangs, sun control elements, parapets, screening elements architectural precast elements.

- Floor, ceiling, and roof systems including but not limited to:
- Appropriate structural items listed below if not provided by the Structural Engineer and integrated into the architectural model for coordination and document generation. Insulation, ceiling systems, and floor are to be included.
- Roof, floor, and ceiling slopes, if needed, shall be modeled.
- Soffits, openings, and accessories shall also be modeled.
- Elevators, stairs, ramps including railing systems.
- Casework, shelving, and other interior architectural elements.
- Furnishings, fixtures, and equipment if not provided by others and integrated into the architectural model for coordination and document generation.
- Furniture (Fixed and Loose).
- Furniture Systems.

- Specialty equipment (food service, medical, etc.).
- Model mechanical, electrical, and plumbing items that require architectural space (toilets/sinks/etc.), require color/finish selection (louvers, diffusers, etc.) or affect 3D visualization (lighting fixtures) unless provided by Engineers.
- Clearance zones for access, door swings, service space requirements, gauge reading, and other operational clearance must be modeled as part of all equipment and checked for conflicts with other elements.

6.3 BIM Models and Deliverables

Models submitted to WPI as a deliverable must meet the requirements of the agreed upon **WPI BIM Execution Plan**. Internally, WPI has standardized its BIM environment on existing work done on BIM and models created for projects are expected to work within WPI's CAD/BIM environment.

6.3.1 Use of Revit and NavisWorks

It is recommended that models are created in the most current versions of Autodesk Revit or Autodesk NavisWorks. Modeling practices are declared in the project's BIM Execution Plan and best practices for model creation can be based on existing BIM models of campus buildings

- Naming conventions of models delivered to WPI should closely follow the naming conventions outlined in this document.

7 ARCHIVAL PRINT FILES AND FORMATS

The idea of maintaining of Archival Print Files is to receive a file with complete details to recreate 100% of the information contained in the hard copy original, without creating an excessively large digital file. These files must be in PDF format and they may be produced either directly from CAD/BIM applications or from a scanned hard copy.

Regardless of production method, the Archive Print Files must match the content of the materials being submitted at closeout. The names of these files must also be the same as the DWG files they represent. All Archival Print Files must follow these production requirements and must be listed with their DWG counterparts as listed in this document.

7.1 PDF File Creation

PDF files can be created from DWG or REVIT files must mirror the color and line thickness that were represented by the print products. To create these files, the same print settings should be used to generate the PDF files. Unless colors are used in the files, PDF files with AutoCAD layer colors instead of their line settings will not be accepted since this is not a true representation of the project documentation.

8 INFRASTRUCTURE NEEDS

While the guide primarily focuses on the process of BIM implementation, it is necessary to procure additional infrastructure to support those process changes. The infrastructure needs should consider the BIM uses, processes, and information needs of the organization. The infrastructure that an organization should consider includes software, hardware, and physical spaces.

Software (Technical):

- Selecting the hardware/software package
- Compatibility with existing systems
- User friendly

Software (Non-Technical):

- Cost of software
- Choice of a widely used/popular software

Vendor (Technical):

- Technical support
- User training

Software Systems:

- Planning, Design, Construction Software's
- Facility Management Systems

Supporting Hardware Systems: Not having the proper hardware to support the software systems can lead to challenges and frustration when implementing and integrating BIM. It is essential that WPI understands the hardware specifications of the computers on which models are created.

- Important to support chosen software
- Choice of devices, workspace

9 EDUCATION AND TRAINING

9.1 Education

Education is critical to help members of WPI organization better understand BIM and the organization's purpose for using BIM. The organization will develop a consistent education program for the staff about the true capabilities of BIM and to educate the staff about BIM.

- Education is critical to helping an organization better understand BIM and the organization's purpose for using BIM.
- Important to convey what is Building Information Modeling and how can BIM be used. This is important especially for new users.
- Organization's purpose for including BIM mission statements and the strategic BIM Plan.

9.2 Training

BIM training will relate to a specific process and software system (Revit). Before any training takes place, a training strategy should be established. The training strategy should include:

- What subjects to train on: The training subjects will include new and existing organizational business processes and procedures, and new and existing software systems.

- Who needs what training: Not everyone in the organization needs to be trained on every software system or business process. It is only necessary to train on the purpose of an activity rather than on how to perform the activity themselves.
- What are the methods to achieve the necessary training: The methods of training can be both internal and external. Often a software vendor will provide training with the purchase of software or for an additional fee. This may be necessary if no one in the organization has prior experience with the software. The training itself can take place in a classroom setting or on a website with tutorials. The training needs will vary based on the size of the group and scope of the BIM adoption. It is up to the group to determine to what extent and by what method are education and training necessary.

10 PILOT PROJECT SAMPLE

10.1 Project 1: Project Center

The Project Center is one of the complete projects that have utilized BIM on campus. The FM department uses the model for maintaining this facility. The following figures are reference for future projects and indicate the final drawing deliverables expected on a project.

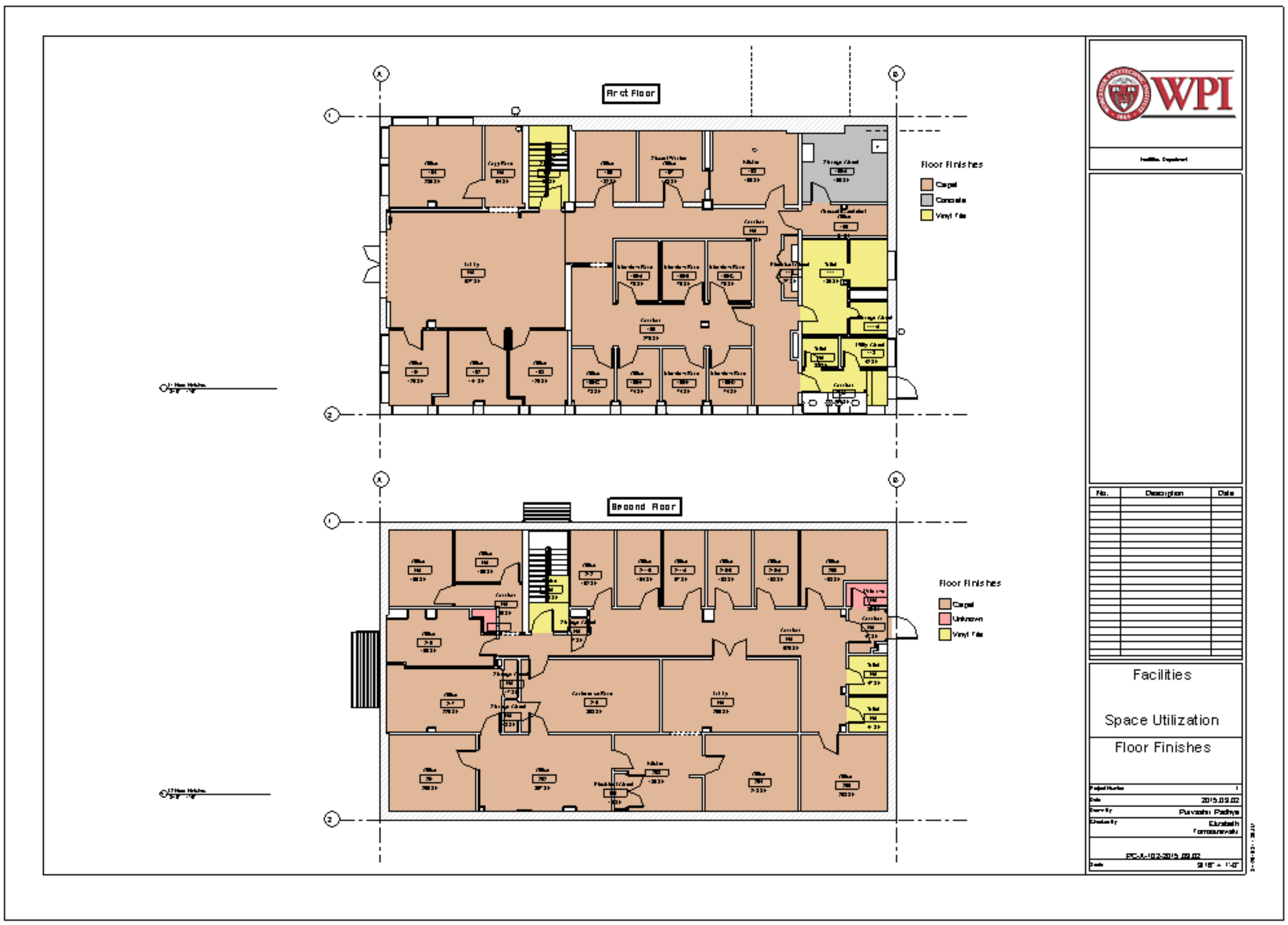


Figure 2: Project Center: Drawing sheet indicating Floor Finishes

Figure 3: Project Center: Drawing sheet indicating Ceiling Finishes

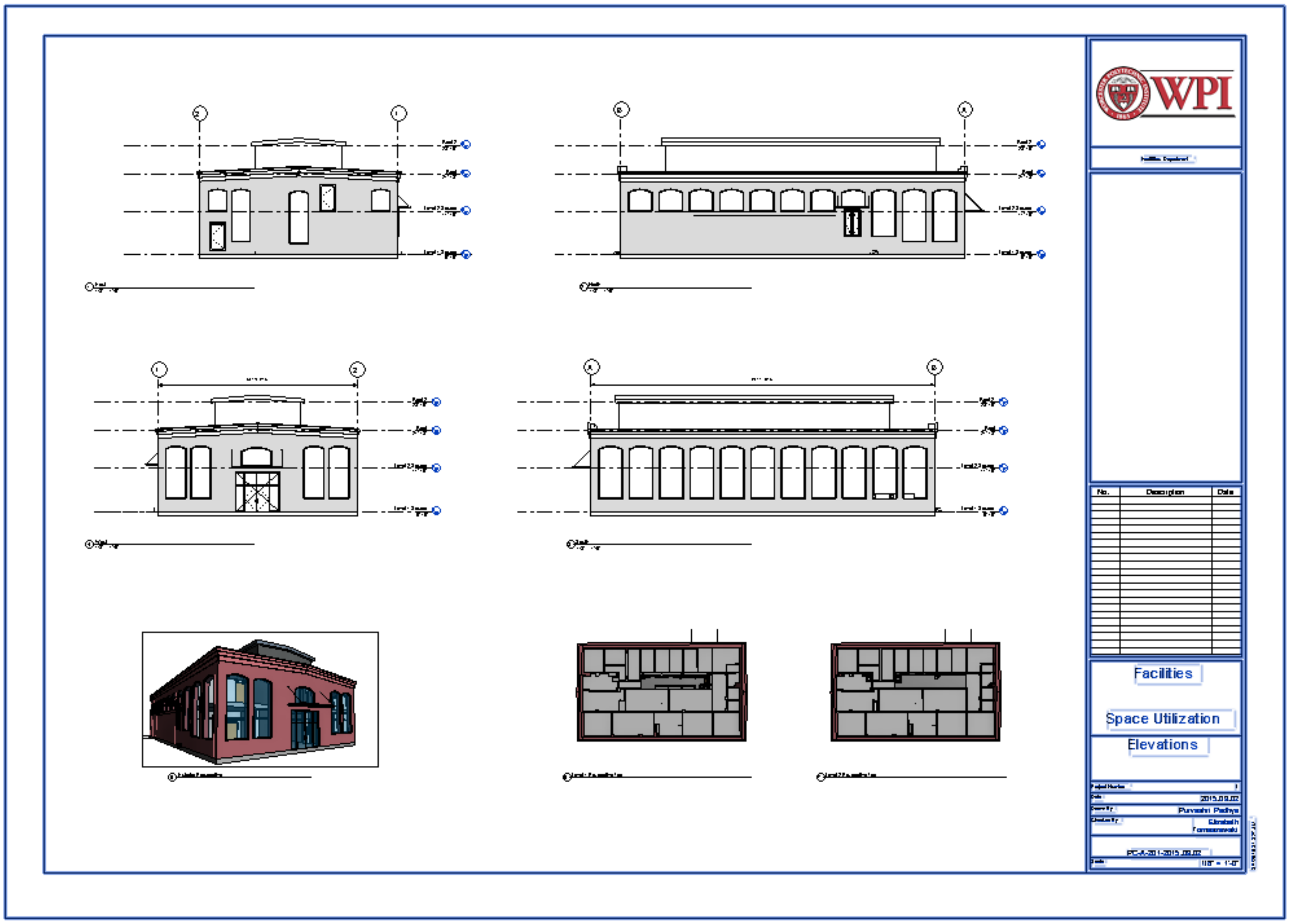


Figure 4: Project Center: Drawing sheet indicating Architectural detailing

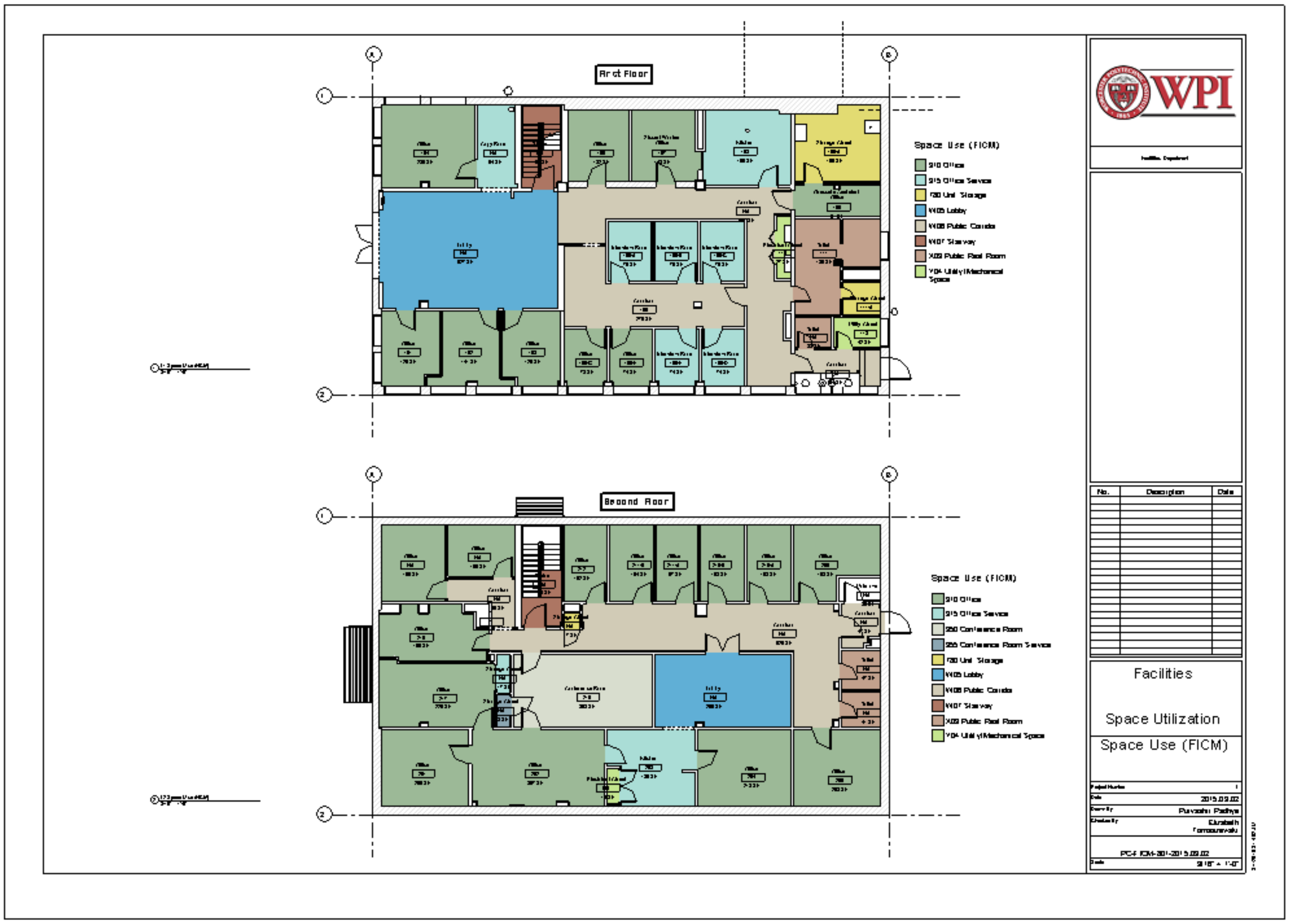


Figure 5: Project Center: Drawing sheet indicating Space Use per FICM codes

Figure 6: Project Center: Drawing sheet indicating Space Use (door tags)

Figure 7: Project Center: Drawing sheet indicating Space Utilization and room capacities

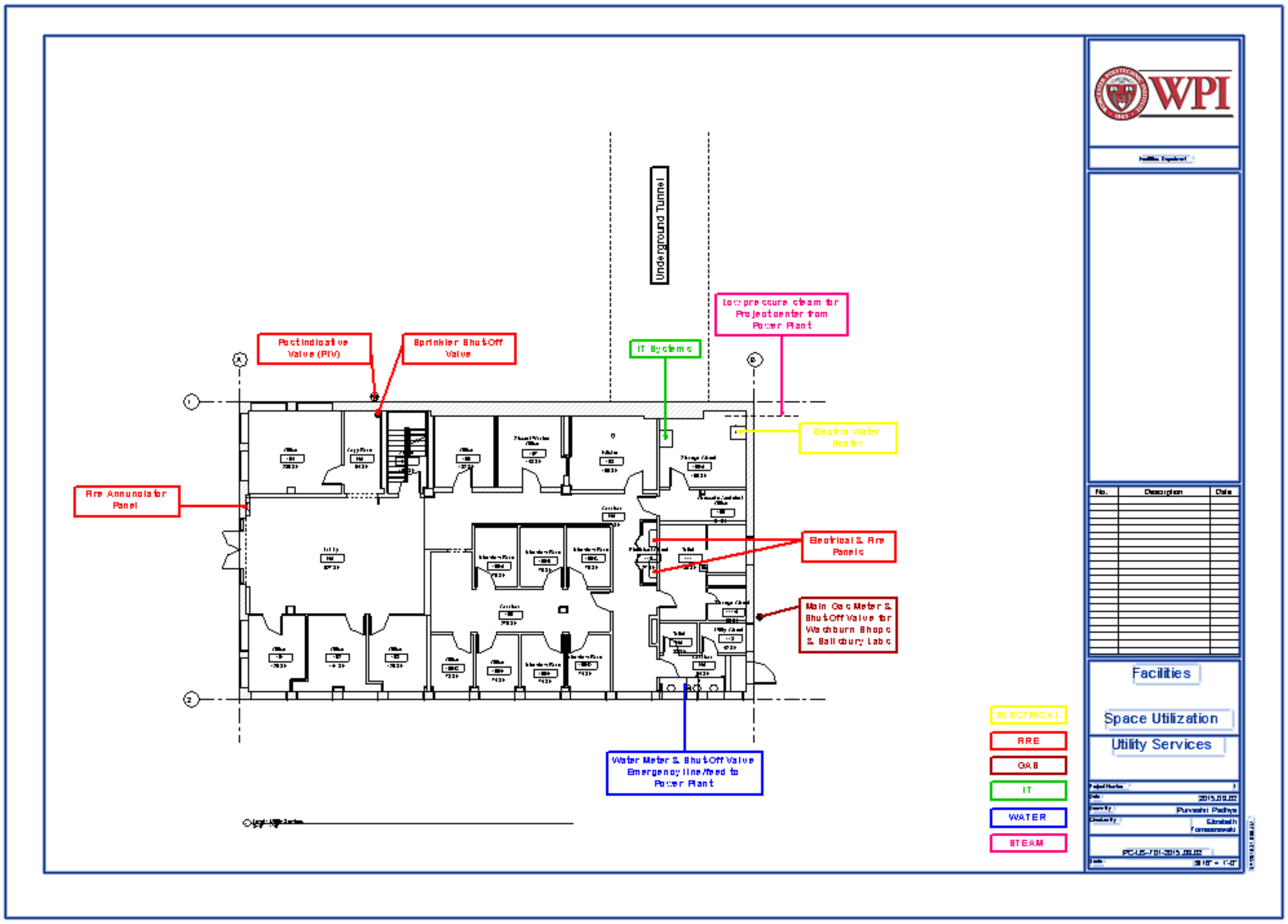


Figure 8: Project Center: Drawing sheet indicating MEP Utilities and locations

Bibliography

https://www.specifiedby.com/resources/bim-dictionary

National BIM Standard-United States [online] Available at:

https://www.nationalbimstandard.org/files/NBIMS-US_FactSheet_2015.pdf

2012 BIM Smart Market Report: Business Value of BIM in North America [online] Available at:

https://oliebana.com/2012/12/09/2012-bim-smart-market-report-business-value-of-bim-in-north-america/

Terminology

A

As-Built Documents

As-built documents are the collection of paper drawings or electronic drawings that typically reside in the contractor's onsite trailer that contain mark-ups, annotations, and comments about changes that have been made to the contract documents during the construction phase.

As-Built Model

Design Intent Models that have been updated throughout the construction process. These changes and updates have been communicated from the Contractor to the Design Team through the comments, annotations, and mark-ups from the As-Built Documents. These typically, but not always, are discipline specific models.

B

BIM Execution Plan (BEP)

A plan that is created from the WPI BIM Execution Plan Template that is to be submitted thirty days after contract award. The BEP helps to define roles and responsibilities within a project team.

BIM Proficiency Matrix (BPM)

A matrix designed to measure the expertise of a firm as it relates to using a BIM process on projects. It will be used as one of the many selection criteria during the selection process.

C

COBie - Construction Operations Building Information Exchange

COBie is a standard of information exchange that allows information to be captured during design and construction in a format that can be used during the operations of a building once completed.

Critical Path Modeling

Critical Path Modeling is a method of demonstrating Integrated Project Delivery, and tied to the AIA E202 level of development approach. It sets a plan within the design team that accounts for the activities of each discipline and how they interact with each other. It builds upon a critical path method for those activities, and allows the project team to schedule a complete project.

D

Design Team

The Design Team is considered the Architect and all of the consultants that provide design services for a project. These design services can be rendered at any time during the project.

DWF

DWF is a file type developed by Autodesk to be locked and non-editable file for drawing sheets and model data. It can be used as a file transfer for estimating data, markups, and other third party software. It can be a combination of 3D and 2D information within the same file.

DWG

DWG is a native AutoCAD file format. It is a widely-used3 file format for exchanging drawing information and 3D information to different programs. While not a database file type, it still has lots of uses for exchanging information.

E

EIM - Energy Information Model

EIM is a concept of producing a “light” and “lean” model that can be used for simulating the building’s performance very early within the design process. The EIM is the process of modeling only the exterior envelope, and the interior volumes to produce a model that energy modeling software can use.

F

FICM - Post Secondary Facilities Inventory and Classification Manual

FICM is standard that describes practices for initiating, conducting, reporting, and maintaining an institutional facilities inventory.

I

IPD - Integrated Project Delivery

IPD describes a contractual relationship between all members of the project team including the Owner, Designers, Consultants, and Construction teams. It is a project delivery method that integrates people, systems, business structure and practices into a process that collaboratively harness the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction.

IPD Methodology

IPD Methodology is a concept that uses methods from the IPD contracts, but does not have the contracts actually in place. It idealizes the concepts of integration of all team members to try and benefit the entire project.

IPP Methodology Plan

The IPP Methodology Plan is a declaration of how the project team will achieve the goals of an IPP Methodology. The plan can have several components and is encouraged to be part of the BEP. The completion of a Reverse Phase Schedule or Critical Path Modeling is two examples of an IPD Methodology Plan.

L

LEED

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is a suite of standards for environmentally sustainable construction. Based on a point system, a building can achieve different ratings based on the performance of the design, construction, and operation of the building.

N

NavisWorks

NavisWorks is software that allows for the viewing of multiple model formats. This ability to "view" these files also allows NavisWorks to simulate the interaction between model files. That includes interference reporting, time lining, and coordination.

NWC

An. NWC file is a NavisWorks Cache File that is used by NavisWorks to quickly read many other file types. All linked files in NavisWorks have an .NWC file created automatically. In addition, Revit will export directly to the very small file type of .NWC for quick access by NavisWorks.

NWD

A much larger file than the .NWC, the .NWD file shows snapshots in time of a NavisWorks file. No linked files exist but all geometry is included.

NWF

The .NWF file is a native NavisWorks file that has all linked files, interferences/ collisions, markups, animations, schedules, etc.

O

Open Architecture

Open Architecture is a concept of creating a framework that helps to describe a common set of rules for how a project is created. This includes what types of software, the interoperability of the information, and how the participants interact with each other. This is different from open standards in that it promotes progress while not anchoring forward thinkers to a rigid standard.

P

Phases

The phases of a project can be described in two different ways as the adoption of IPD terminology starts to penetrate the BIM Execution Plan and the IPD Methodology Plan. Below is a list of the traditional names followed by the IPD name.

Pre-Design/Conceptualization Phase

Schematic Design/Criteria Design Phase

Design Development/Detailed Design Phase

Construction Documents/Implementation Phase

Project Team

The Project Team is considered the combination of the Design Team, Contractor, and at times, GT faculty; a complete team needed to make holistic project decisions and approvals.

R

Record Drawing

The production of Record Drawings is the capturing of the As-Built Document's annotation, comments, and mark-ups in a drawing format only. This does not typically include the updating of any models.

Reverse Phase Scheduling

Reverse Phase Scheduling Is a method of demonstrating Integrated Project Delivery. It sets a plan within the design team that accounts for the activities of each discipline and how they interact with each other. It uses the completion date as a point to work backward from to schedule all of the project's activities.

RVT

An .RVT file is a Revit native file type. It is also the deliverable file format for all projects. This includes all the Design Team's models.