The difference in BIM component data requirements between prescriptive representations and actual practices

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ABSTRACT

Utilizing Building Information Modeling (BIM) for Facility Management (FM) can reduce interoperability costs during the Operations and Maintenance (O&M) phase by improving data management. However, there are technological, process related, and organizational barriers to successful implementation of BIM integrated FM (BIM-FM), and process related barriers might be solved by the use of BIM integrated FM (BIM-FM) guidelines. However, the guidelines need to be updated with lessons learned from actual practices in order to maintain their validity. In order to diagnose current practices and identify key differences between prescriptive representations and actual practices, this exploratory research compares BIM component data requirements between guidelines and actual practices at public higher education institutions in Virginia. The gap in BIM component data requirements between the guidelines and the actual practices may prevent successful implementation of BIM-FM. This research is composed of three parts: a synthesis of prescriptive representations, determination of actual data requirements in practice, and comparison of differences between guidelines and practices. Document analysis and case study via document analysis and in-person interviews were conducted to collect data. Then, direct comparison was conducted to test the research question. Though the researcher disapproved the established hypothesis of "There would be some differences in BIM component data requirements between prescriptive representations and actual practices" due to the difference in level of information and details between prescriptive representations and actual practices, this exploratory research provides useful information.

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1. Introduction

Although the initial construction cost of a capital project is of primary concern to owners and project stakeholders, downstream operations and maintenance (O&M) costs take the largest fraction of the total costs of a building's life cycle. According to a research study conducted by Christian and Pandeya, where 14 university facilities and 8 government offices were investigated, the life cycle cost of the operational portion of the building was 60% to 85% of its total ownership cost, whereas design and construction accounted for about 5% to 10% (Christian et al. 1997). Acquisition, renewal, and disposal costs were between 5% and 35% of the total ownership cost (ibid.).

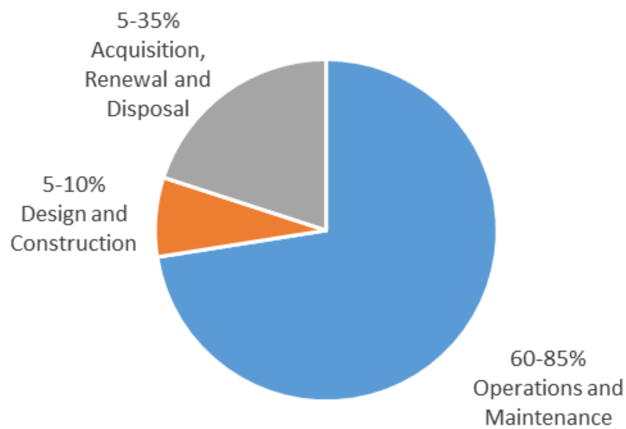


Figure 1: Life cycle cost for nonresidential buildings (Christian et al. 1997)

Educational facility construction is the biggest sector of non-residential construction (Giggard 2014). In New York City, more than $643 million in public and private higher education development projects were delivered during the first five months of 2014 (McGraw Hill Construction 2014). This large investment in educational facilities is related to demographic trends. From 1995 to 2010, the number of students enrolling for higher education has been continuously increasing, and 120,375,789 students were enrolled for higher education in 2013 (Snyder and Dillow 2015). In order to attract more students, higher education institutions are improving their facilities (Almeida 2002).

Public higher education institutions have distinctive characteristics as institutions providing higher education and utilizing public funds. Regardless of heterogeneous facility types, which makes it difficult to establish a comprehensive facility management plan, there is a special motivation for facility improvement in higher educational institutions due to the distinctive educational service they provide. However, stringent and overlapping procurement regulations on publicly funded educational institutions act as constraints in the decision making process requiring considerable amount of resources and documentation. Therefore, facility management in public higher education institutions has some unique opportunities and challenges, which makes those institutions valuable research subjects.

In order to manage facilities effectively, facility managers require information about facilities they manage. In his paper, Jawadekar argues that information is the most important resource to facility managers, and it is required before any of the other resources can be properly managed (Jawadekar 2012). Adequate and accurate information is the first thing that facility managers need in order to manage facilities effectively and efficiently.

However, information management during the O&M phase is known for its inefficiency. According to a report from National Institute of Standards and Technology (NIST), $15.8 billion annual cost occurred related to information interoperability and most of this cost was generated during the O&M phase of facilities (Gallaher et al. 2004). In other words, effective information management can save significant costs during the O&M phase.

Building Information Modeling (BIM) can be a solution for reducing interoperability costs during the O&M phase. BIM is "a new approach to design, construction, and facility management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format" (Eastman et al. 2008). Generating a building information database along with the project process, BIM enables management and communication through both 3D digital representation of building system (model) and project data among not only collaborating companies, but also within individual companies. Extending the use of BIM to the O&M phase ensures continuous utilization of facility data generated throughout the design and construction phase. Valuable facility data such as material information, warranty information, model numbers, manufacturer, fire rating information, and asset numbers can be saved within BIM in a structured way and transferred to data management systems which support facility management (FM) like FM information systems.

There are some tools supporting owners and facility managers to establish a BIM plan for FM purposes, but facility managers and owners have been reluctant to adopt BIM in FM. Becerik-Gerber and co-authors conducted an online survey to determine the respondents' level of awareness, experience, and interest regarding the application of BIM in FM. In total, 77 participants from various FM organizations responded. In this survey, where the respondents could choose multiple answers, most of the participants who had experience with BIM indicated that they have utilized it in the design phase (83%), followed by the construction phase (79%). Only 42% of the respondents indicated that BIM was used in the O&M phase (Becerik-Gerber et al. 2011).

The first step for successful utilization of BIM for FM is to define the data requirements (Liu and Issa 2013). Types of data and their formats embedded in BIM are decided by owners and FM staff at an early phase of a project to ensure correct data collection at the right time during the project (Teicholz 2013). Moreover, predefined data requirements allow creation of useful BIM for successful data transfer between BIM and FM information systems.

Despite of the existence of prescriptive guidelines regarding data requirements for BIM integrated FM (BIM-FM), few organizations have successfully leveraged BIM for FM (Becerik-Gerber et al 2011; Jawadekar 2012; Teicholz 2013). There is a disconnection between how guidelines recommend preparing BIM for the O&M phase and how it is actually formed and used. What are the differences in BIM component data requirements between prescriptive representations and actual practices at public higher education institutions?

This exploratory research analyzes BIM data requirements in prescriptive representations as well as actual practices and identifies key differences. Four guidelines and three universities were investigated in this study. The study is a first step toward testing the hypothesis that discontinuance between prescriptive representations and actual practices may hinder successful implementation of BIM-FM.

2. Background

One of the main benefits of utilizing BIM during the O&M phase is to provide initial data to FM information systems and serve as a reliable information data storage of a facility's history, including most current updates. Here, BIM acts as a data provider and storage center to support data management at the O&M phase. On the other hand, FM information systems support facility managers' day to day work activities such as managing work orders, publishing preventative maintenance schedules, reporting, and managing/updating assets and inventory.

This chapter explores concepts and terms related to data transfer between BIM and FM information systems to improve interoperability during the O&M phase at public higher education institutions. Importance of FM in public higher education institutions, BIM component data, initial data input to FM information systems, Construction Operations Building information exchange (COBie), BIM integrated FM (BIM-FM), Guidelines, and Current practices of BIM-FM are discussed in this chapter.

2.1. Importance of FM in public higher education institutions

Facility management in public higher education institutions has unique opportunities and challenges due to the distinctive characteristics of higher education institutions and public organizations. They have special motivations to improve their facilities due to the educational service they provide. However, their diverse operational needs bring challenges in establishing an organizational facility management plan. In addition, as publicly funded educational institutions, public higher education institutions are applied to multiple procurement regulations which burden their decision making process requiring considerable amount of resources and documentation.

Improved facility management performance in higher education institutions is expected to bring positive impact on the efficiency of education, which is one of the particular interests of policy makers. Research on facility management is based on an assumption that the physical environment in which an organization operates affects the efficiency of the organization. In other words, improved environment of an organization can increase the efficiency of the organization (Amaratunga and Baldry 2000). The advancement of the manufacturing industry has been observed in many countries and is related to the improvement in facilities, and studies report that many management strategies on higher education establishment have focused on improving physical environment (facilities) (ibid.). In 2012-2013 academic year, more than $62 million of federal funds were put into public higher education institutions (Snyder and Dillow 2015). Policy makers seek to find a way to maximize the value of education cost. Though it is difficult to quantify the impact of facilities on educational effectiveness, it is assumed that that progress in facilities of higher education institutions would increase the effectiveness of the educational service that they provide. This expectation acts as a special motivation for facility improvements in higher education institutions.

However, facility management in higher education institutions possesses challenges because such facilities are comprised of wider range of buildings with different operational needs, which makes it difficult to establish an organizational facility management plan (Amaratunga and Baldry 2000). Modern universities not only have classrooms to support educational and academic activities, but also laboratories to conduct various types of research in a controlled environment. Residential facilities like dorms, commercial facilities like cafeterias and bookstores, athletic facilities like gyms and stadiums, concert halls, hospitals and medical centers, utility facilities like power plants, parking structures and grounds, and multitude of office buildings with different operational purposes, also add up the variety of facilities that higher educational institutions have. This diverse operational need brings challenges in making a comprehensive facility management plan at organizational level.

On the other hand, unlike private education institutions, publicly funded education institutions are subjected to multiple policies and procurement requirements, which act as constraints in decision making process and limit their autonomy. For example, publicly funded colleges and universities in Virginia are required not only to support the mission of higher education and but also to comply with the principles of the "*Virginia Public Procurement Act*" and "*Rules Governing Procurement of Goods, Services, Insurances, and Construction by a Public Institution of Higher Education of the Commonwealth of Virginia (The Governing Rules)*". They encourage the institutions to flexibly design competitions for all of their purchases yet in fair and transparent manner in order to maximize the value of public funds. The Governing Rules mention "competition be sought to the maximum feasible degree", "procurement procedures involve openness and administrative efficiency", and "individual public bodies enjoy broad flexibility in fashioning detail of such competition". All the decisions regarding purchases cannot be solely made by an organization, but rather through an open, fair, and impartial competition (VASCUPP 2014).

Furthermore, the overlapping oversight structures of publicly funded education institutions and their strict constraints make public education institutions undergo a lot of effort and caution in the procurement process, as a result generating considerable data. Overlapping oversight structures are common in publicly funded education institutions since they have a variety of funding mechanisms at various levels of government (Wirick 2009). The total budget of a public university may be funded by the state government and the federal government, each of which may have its own oversight structures. This requires substantial resources and documentation for ensuring the compliance with each constraint. In addition, the consequences and disadvantages from violating these constraints are so significant that "the organization may be very risk averse, even to the extent of choosing compliance over the attainment of business objectives (Wirick 2009)."

In short, facility management in public higher education institutions is an important research subject due to the distinguishing characteristics of these types of facilities. Although it is difficult to establish organizational facility management plans due to diverse operational needs, public higher education institutions have a special motivation towards facility improvement as institutions providing higher education services. At the same time, public higher education institutions are subjected to multiple policies and procurement requirements, which often overlap. This results in constrains that require additional resources and documentation in project procurement of public higher education institutions. Therefore, these distinctive conditions put public higher education institutions as a subject of worthy investigation.

2.2. BIM component data

BIM is an emerging technology with considerable potential to enhance facilities management within the challenging environment of public higher education institutions. BIM can host 3D models that represent building systems with data being embedded in each building component representation. This embedded data is called 'BIM component data'. For example, when a BIM model has a door as a component, the door can host vast information such as material information, warranty information, model number, manufacturer, fire rating information, and asset numbers as shown in Figure 2.

The types of data needed by FM staff to manage their facilities properly can be saved in BIM in the form of BIM component data and exported for various purposes. During and after the construction phase, facility managers receive information such as warranty information, subcontractor/vendor contacts, maintenance information, training, drawings, submittals, product data/samples, regulation/legal issues, building systems information, equipment information and material/finishing information, specifications, operation and maintenance information, and contract and commissioning information (Thomas-Mobley and Khuncumchoo 2006). This information can be saved in the form of BIM component data, from the moment they are generated during the design and construction phase. Since much or all of this information is saved in digital format, BIM component data containing useful information for FM can be exported for various purposes like initial data input to FM information systems.

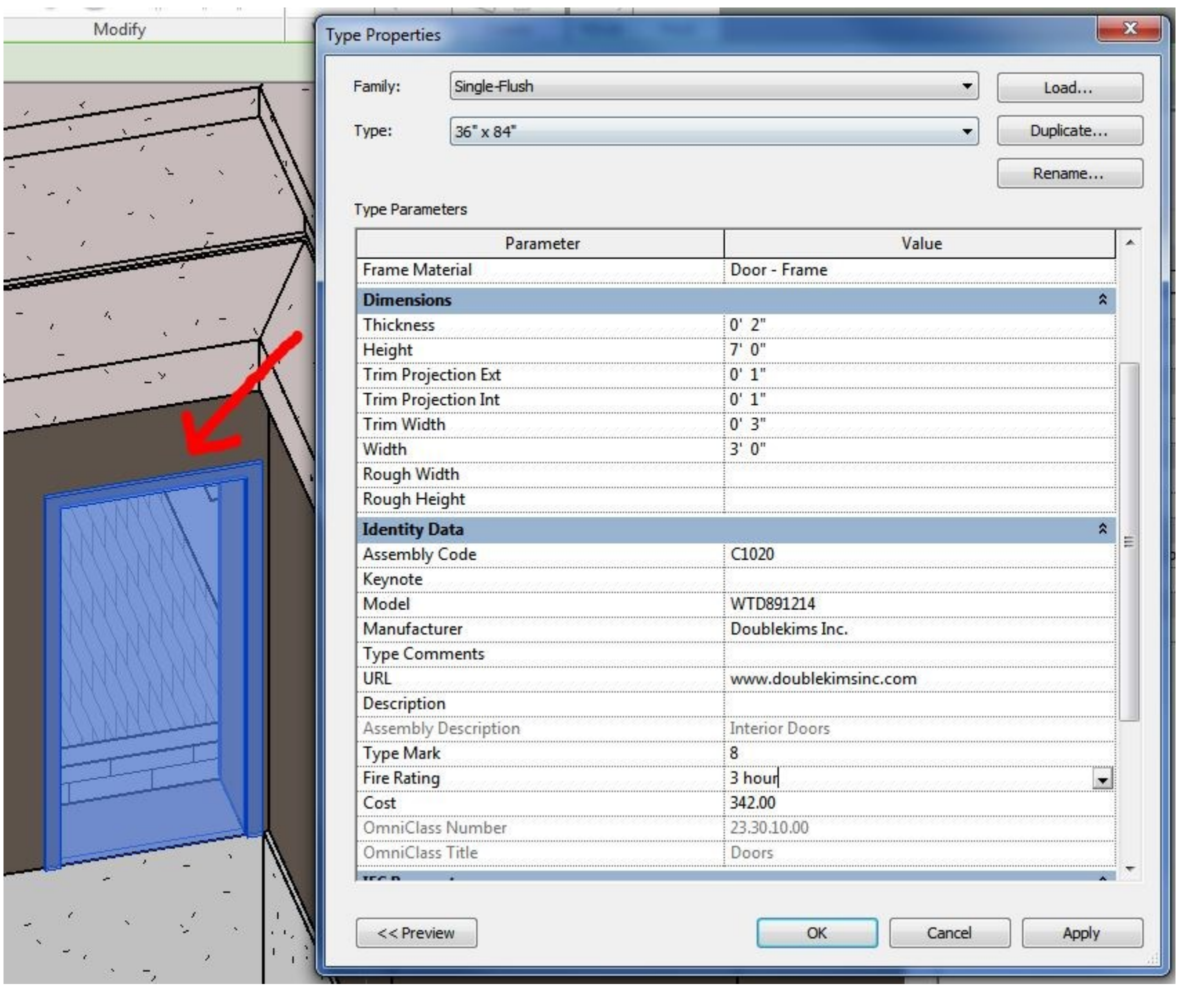


Figure 2: BIM component data for a door example

2.3. Initial data input to FM information systems

FM information systems are software tools, which support FM practices. For example, computerized maintenance management systems (CMMS) gather and save information for FM and help managing facilities by providing reporting and analyzing tools. Electronic document management system (EDMS) support documentation for facility managers by organizing and storing various types of documents that are generated throughout the facility's O&M phase. Energy management systems (EMS) monitor and control energy performance, and building automation systems (BAS) automatically monitor, control, and record electronic devices such as lighting, security, HVAC, and humidity control to keep the indoor environment at a constant level.

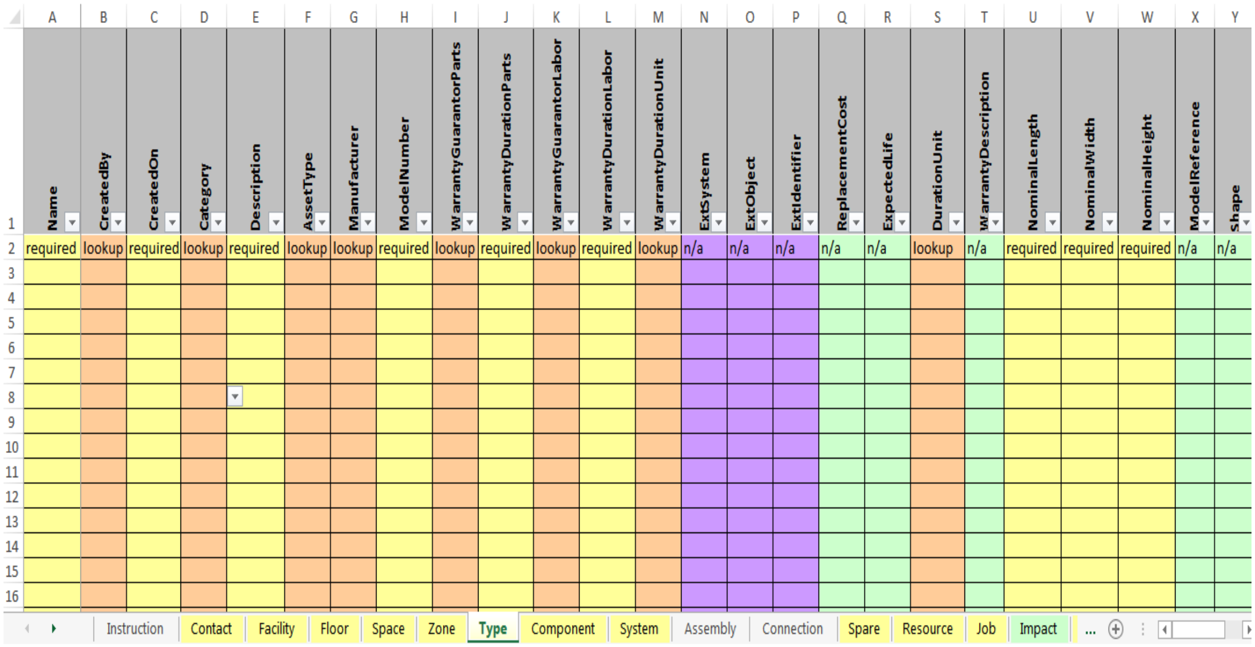
In order to manage facilities using FM information systems, facility managers have to input initial data required by these systems. Historically, the data has been entered manually after the handover of a facility, which is a tedious, inefficient, and time-consuming process (Becerik-Gerber et al. 2011). Since most of the 'operational information' is handed over in the form of paper based documents or electronic versions of paper based documents at the end of the construction phase, facility managers analyze these documents and enter the required data into FM information systems. Also, incompatibility between FM information systems burdens facility managers and makes them reenter the same data to each program multiple times (Becerik-Gerber et al. 2011).

BIM component data can be captured from BIM and then imported to FM information systems when adequate and sufficient information is collected in a compatible manner with FM information systems, in a process known as Construction Operations Building information exchange (COBie) (Anderson et al. 2012).

2.4. COBie

The Construction Operations Building information exchange (COBie) functions as a standard that supports the collection of facility's asset data (Teiholz 2013). As a National Building Information Model Standard – United States (NBIMS-US) information exchange standard, COBie identifies and exchanges FM associated data from the planning of a project, until the demolition (Bogen 2014). There are two COBie formats, Industry Foundation Classes (IFC) and COBie Spreadsheet, and this makes COBie compatible with both BIM software and FM information systems.

In the most recent version of COBie, COBie spreadsheet 2.4, a COBie-compliant Excel file is composed of 18 worksheets. Each worksheet helps capturing project data from different facility life cycle phases and consists of attributes to be filled. Figure 3 is a screen shot of common COBie spreadsheet. Columns are color-coded by 6 categories. Yellow means 'required', orange means 'reference to other worksheet or pick list', purple means 'external reference used if data is created from software, may contain pick list to allowed IFC objects', green means 'required, if specified', grey is used for 'visual cue for headings', and finally, white means 'not required for the given phase'.



Name	CreatedBy	CreatedOn	Category	Description	AssetType	Manufacturer	ModelNumber	WarrantyGuarantorParts	WarrantyDurationParts	WarrantyGuarantorLabor	WarrantyDurationLabor	WarrantyDurationUnit	ExtSystem	ExtObject	ExtIdentifier	ReplacementCost	ExpectedLife	DurationUnit	WarrantyDescription	NominalLength	NominalWidth	NominalHeight	ModelReference	Shape
required	lookup	required	lookup	required	lookup	lookup	required	lookup	required	lookup	required	lookup	n/a	n/a	n/a	n/a	n/a	lookup	n/a	required	required	required	n/a	n/a

Figure 3: An example of COBie file

Table 1 specifies the attributes of each worksheet classified by categories. Only the required attributes are included in the table. Since COBie acts as a bridge between BIM software and FM information systems, it is possible to automatically transfer data to each other if a BIM model contains COBie compliant BIM component data.

Table 1: Summary of required COBie data in COBie spreadsheet 2.4 (Adapted from GSA 2011 and COBie spreadsheet 2.4.)

Categories	Worksheets	Contents	Required Attributes
Spaces	Facility	Project, Site, and Facility. COBie data is delivered in one file per facility.	Name, Area Measurement
	Floor	Vertical building levels, Site and Roof	Name, Created On
	Space	Spaces listed in floor plans/finish schedules, and Roof/Site locations for managed equipment.	Name, Created On, Description
	Zone	Sets of spaces sharing a specific attribute	Name, Created On
Products/Equipment	Type	Types of equipment, products, and materials identified in design schedules.	Name, Created On, Description, Model Number, Warranty Duration Parts, Warranty Duration Labor, Nominal Length, Nominal Width, Nominal Height
	Component	Individual instances of equipment, products and materials	Name, Created On, Description, Serial Number, Installation Date, Warranty Start Date
	System	Sets of components providing a service	Name, Created On
	Assembly	Differs based on project conventions	No attributes required
	Connection	Differs based on project conventions	No attributes required
Operations and Maintenance Worksheets	Spare	Onsite and replacement parts	Name, Created On
	Resource	Required materials, tools, and training	Name, Created On
	Job	PM, Safety, and other job plans	Name, Created On, Description, Duration, Start, Frequency
	Impact	Economic, Environmental and Social Impacts at various stages in the life cycle	Name, Created On, Value
All Phases	Contact	People and Companies referenced in the COBie data set	E-mail, Created On, Company, Phone
	Document	All applicable document references	Name, Created On, Directory, File
	Attribute	Values corresponding to design schedules for Spaces, Products, and Equipment	Name, Created On, Value, Unit
	Coordinate	Differs based on project conventions	No attributes required
	Issue	Differs based on project conventions	No attributes required

2.5. BIM integrated FM (BIM-FM)

When BIM, COBie, and FM information systems are combined, information can be transferred seamlessly not only between BIM and FM information systems but also among different FM systems (Anderson 2012; Becerik-Gerber et al. 2011). This integration of BIM and FM information systems through open formats such as IFC or COBie is called ‘BIM integrated FM’ (BIM-FM).

Specifically, with BIM-FM, facility managers can import FM information from BIM files in COBie formats. This implies that facility managers are able to put the exported BIM component data into FM information systems and vice versa for updating BIM with latest FM information. This automatic data transfer saves time, energy, and cost from the conventional manual data input and reduces human errors (Becerik-Gerver et al. 2011). Figure 4 describes the data exchange between BIM and FM information systems through COBie.

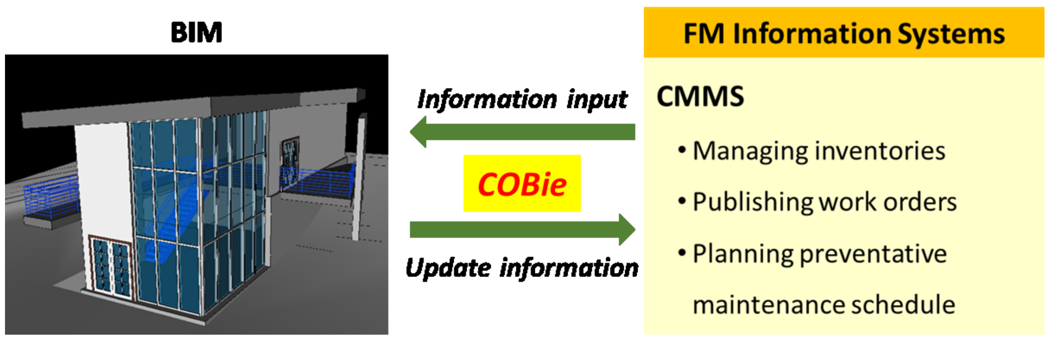


Figure 4: Data exchange process between BIM and FM information systems

In addition, BIM-FM also improves interoperability issues between different FM information systems. FM information system software is fragmented among various vendors because of market competition and lack of common interests. Therefore, facility managers reenter the same information to different FM information systems (Becerik-Gerber et al. 2011). However, COBie-compliant BIM acts like a bridge for sharing data between different FM information systems. BIM, as a single building database that contains all the updated information, can provide data to different FM information systems. Figure 5 illustrates the relationships of BIM as a single database and a bridge for different FM information systems.

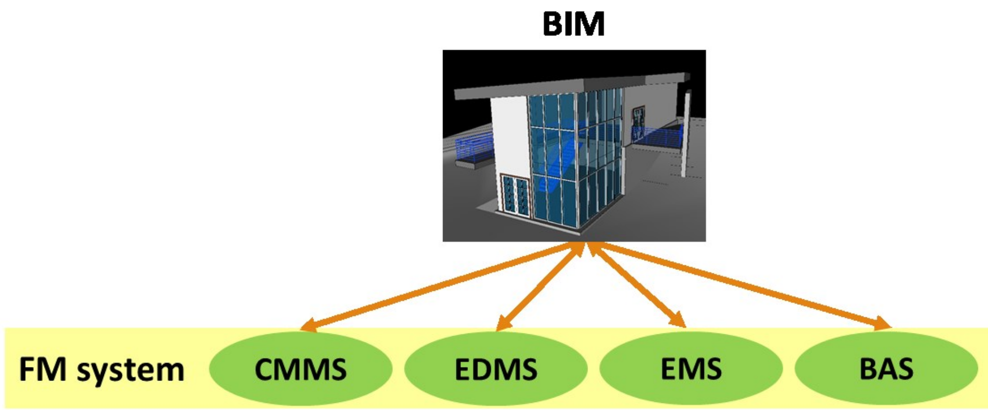


Figure 5: Data sharing among FM systems through COBie compliant BIM

2.6. Guidelines

In order to support BIM-FM planning, there are some prescriptive recommendations and guidelines regarding BIM-FM implementation. Guidelines for owners and facility managers from various organizations such as General Services Administration (GSA), Penn State University, National Institute of Building Sciences (NIBS), University of Southern California (USC), State of Wisconsin, and Los Angeles Community College District (LACC) are some of the examples. Table 2 summarizes mentioned guidelines.

Table 2: Summary of guidelines (Adapted from Teicholz 2013)

	The BIM for FM Guideline	BIM Planning Guide for Facility Owners Version 2.0	National BIM standard-United States™ Version2	Wisconsin BIM Guidelines and Standards for Architects and Engineers, v2	LACCD BIM Standards, v3	BIM Guidelines version 1.6
Source	GSA	Penn State University, Computer Integrated Construction Research Program	NIBS, building SMART alliance	State of Wisconsin, Department of Administration Division of State Facilities	Los Angeles Community District	USC Capital Construction Development and Facilities Management Services
Date released	2011.12	2012.04	2012.05	2012.07	2010.04	2012.04
Applies to	Total building life cycle	Total building life cycle	Total building life cycle	Design, construction, and project turnover	Design, construction, and project turnover; design/build; design/bid/ build	Design, construction; design/bid/ build
Discussion of BIM-FM	Yes	Yes	Yes	No	No	Yes

Most of the guidelines are available online, and facility managers can utilize them when they establish a BIM-FM plan. By using guidelines in advance, they can be familiar with the recommended procedures and customize them according to the condition of their organizations.

2.7. Current practices of BIM-FM

Despite the existence of prescriptive guidelines to assist in the process, utilizing BIM during the O&M phase is still a nascent practice in the FM industry, and there are only a few successful examples of BIM-FM in practices. As mentioned earlier, BIM utilization during the O&M phase (42%) is much lower than the design (83%) and construction (79%) phase (Becerik-Gerber et al. 2011). Furthermore, some organizations, that have decided to make use of BIM during the O&M phase, have struggled to integrate BIM with FM databases.

In the Texas A&M Health Science Center in Bryan project, the construction of useful BIM for FM data formulation started at the last stage of construction, unlike the prescriptive way of doing it throughout the design and construction process. The owner intended to extract FM data from BIM in order to formulate an FM database through COBie. However, since there were no predefined requirements for BIM formulation, architects and general contractors constructed BIM in their own manner. The resulting BIM was not equipped with adequate BIM component data that could be directly transferred to FM information systems. FM data were formulated from scratch instead of reusing the data generated throughout the design and construction phase. In addition, outsourced consultants were hired to formulate FM data from BIM because of the lack of knowledge among in-house staff regarding BIM, open standards for data transfer, and CMMS (Jawadekar 2012).

Meanwhile, in cases such as Peter W. Rodino Federal Building Modernization in Newark, NJ and Bishop Henry Wipple Federal Building in Fort Snelling, MN, facility management groups have suffered from the added COBie requirement when imposed after a project has already begun. COBie requirements for architects and contractors were not a part of the original project contracts. These new requirements and modified specifications brought a lot of confusion and additional costs to the owners. Furthermore, COBie and BIM were nascent concepts to some contractors, and their use resulted in a loss of time and cost for the owners and FM staff to collect FM data from the general contractors (GC) and subcontractors (Teicholz 2013).

Multiple types of software capable of providing data transfer between BIM and FM information system exist. For example, in December 2011, COBie Challenge, an event that encourages the production and consumption of COBie data by Computerized Maintenance Management Systems (CMMS) and Computerized Asset Management Systems (CAMS), was held in Washington, DC. In COBie Challenge, design software vendors succeeded in importing a set of simulated facility management information from common BIM files to CMMS (Zawadski 2012).

Software tools, prescriptive representations, and contracting structures for BIM-FM are available (Lewis and Foster 2013). However, as indicated earlier, utilizing BIM in FM is still nascent to the Architecture, Engineering, Construction, and Operations (AECO) industry.

Is BIM-FM beneficial for FM at public higher education institutions? If so, what are the barriers to BIM-FM implementation?

3. Literature Review

Literature review was performed to address two goals: to confirm benefits of BIM-FM implementation and to investigate barriers to BIM-FM implementation. Next, the researcher performed a gap analysis in an attempt to establish areas that have not been studied within barriers to the BIM-FM implementation.

In order to determine whether or not BIM-FM is beneficial for FM at public higher education institutions, functions and structures of FM organization in higher education institutions were identified. Then, benefits of BIM-FM were found in multiple studies. Finally, benefits of BIM-FM to improve functions of public higher education institutions were identified.

Once the confirmation of benefits of BIM-FM in higher education institutions was completed, the researcher performed an investigation on existing literature about barriers to BIM-FM implementation. Literature about barriers to BIM-FM implementation was classified by three categories, technological, process related, and organizational, to diagnose the distribution of research on barriers to BIM-FM implementation.

3.1. Functions and structures of higher education institutions' FM organization

In any organization, there is an organizational structure so that people can cleverly divide the responsibilities in the direction of maximizing both the individual's and the organization's capacity to meet the organizational need(s). This structure influences how an innovation such as BIM is identified and integrated into the organization's work processes. Organizational structure is composed of organization components, their relationships, and hierarchy (Friday 2003). A well-designed organizational structure enables the organization to channel and manage resources for optimum effectiveness and efficiency (APPA 1997).

A typical FM organizational structure is difficult to find because each FM organization has different functions to perform in order to achieve the goal(s) of the parent organization. The different characteristics of parent organizations determine the functions of the FM organization and its structure.

Several studies suggest the various functions of FM organizations. Table 3 describes functions of a FM organization found in literature. Though a consensus cannot be made due to the variety of organizational needs, the following functions of FM are shared across different literature (APPA 1997; Cotts et al. 2009; Friday 2003):

- Organizational management
- Financial & Budget management
- General administrative services
- Space management
- Real estate management
- Record management
- Facility planning & forecasting
- Facility Design and Construction
    - Architectural & Engineering service
    - Construction management
    - Code compliance
    - Contract management
    - Commissioning
    - Interior design
    - Renovation projects
- Facility maintenance and operations
    - Housekeeping
    - Repairs & Preventive maintenance
    - Utility management
    - Waste management
    - Energy management
    - Ground management
    - Security & Safety
- Transportation services

In addition to the various functions of FM organizations, there are some determinants that influence a FM organizational structure. An organization's profile is the most critical determining factor of FM organizational structure. It includes information of type of the organization, size, types of facilities, location (Single/multiple & Urban/rural), and the organization's mission. Other determining factors found in the literature include: an organization's preference for standard vs. user-driven services, facility manager's place in an organization's hierarchy, contracting out, owned vs. leased facilities, and centralized vs. decentralized decision making (Cotts et al. 2009).

Table 3: Functions and responsibilities of a FM organization found in literature

Literature	APPA 1997	Cotts et al. 2009	Friday 2003
Functions and Responsibilities	• Facilities space administration • Facilities planning • Facilities design and construction • Utilities services • Facilities maintenance • Renovations • Custodial services • Grounds maintenance • Automotive, vehicle, garage • Other services o Solid waste collection and disposal o Fire protection and safety o Real estate services: leasing, appraisal, acquisition, and sale o Security o Risk management o Environmental health and safety o Mail and messenger service o Transportation services: vehicle lease pool, shuttle services	• Management of the Organization • Facility Planning and Forecasting • Lease Administration • Space Planning, Allocation, and Management • Architectural/Engineering Planning and Design • Workplace Planning, Allocation, and Management • Budgeting, Accounting, and Economic Justification • Real Estate Acquisition and Disposal • Sustainability • Construction Project Management • Move, Add, Change management • Operations, Maintenance, and Repair • Technology Management • Facility Emergency Management • Security and Life-Safety Management • General Administrative Services	• Strategic o Short-term planning o Long-range planning o Real estate planning o Financial and budgetary planning • Planning and Design o Architectural and engineering o Construction o Interior installations o Space management • Maintenance and Operations o Preventive maintenance o Housekeeping o Exterior maintenance o Trash removal o Energy management o Landscaping o Computer equipment maintenance • Administrative o Security o Mail o Telecommunications o Copying and printing o Records management o Purchasing o Shipping and receiving o Concierge services o Special services

There were some FM organizational structure models that were discovered in the collected literature. For example, Cotts and coauthors suggest 5 organization models that generally describe FM organizational structures that are observed in practice. Their suggested models are classified mainly by the geographical form of facilities of the institutions. The proposed models are an office manager model where the organization utilizes a single-site leased facility, one location & one-site model, one location & multiple-sites model, multiple location & strong regional/divisional/headquarters model, and fully international models.

As an association of higher education facilities' officers, APPA suggests an example of comprehensive facilities' organizational structure of colleges and universities, where functions of facilities management can be effectively delivered by several organizational components which act as functional groups (Fig 6). The functional groups classified by APPA are management and leadership, executive head of the facilities management organization, business services, work management, facility management planning design and construction, and facilities operation and maintenance (APPA 1997).

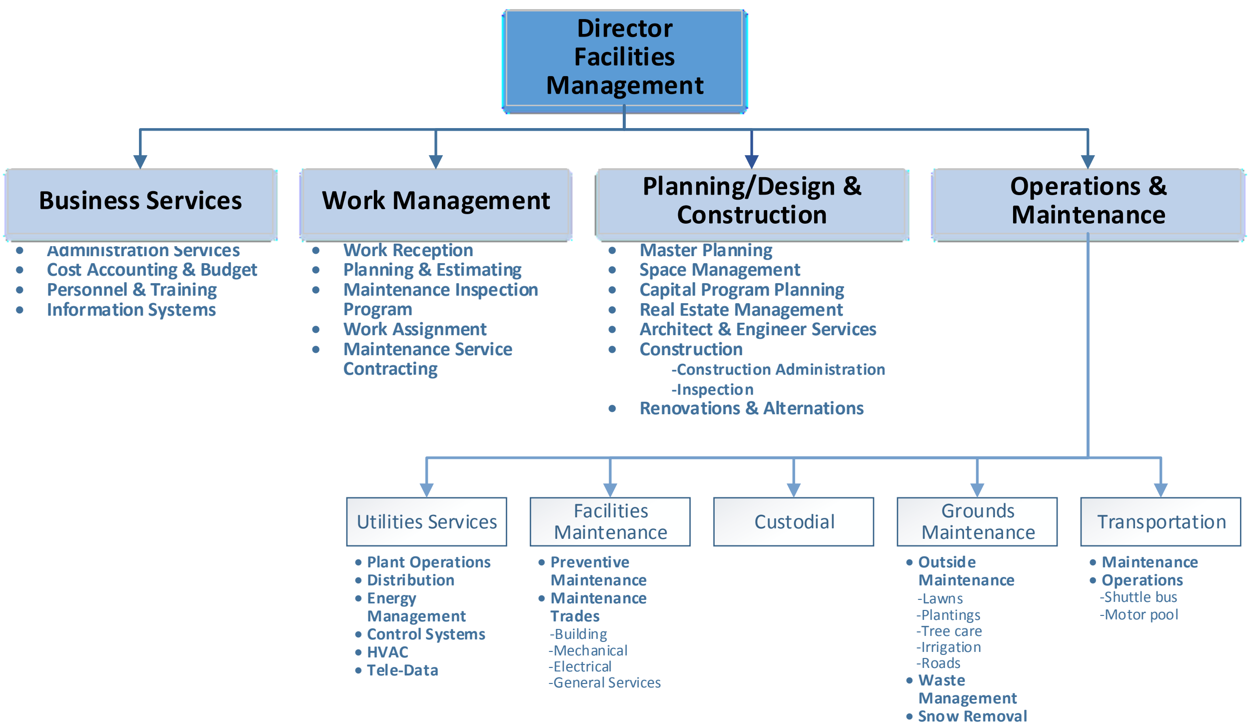


Figure 6: APPA Comprehensive Facilities Organization (Adapted from APPA 1997)

Although various types of FM organizational structure models are found in literature, FM organizational structures of public higher education institutions in this study resemble what is illustrated in Figure 6. Their organizational configuration is differentiated both vertically and horizontally. The organizational configuration is horizontal differentiated by five main functional areas: planning and acquisition, design and construction, the maintenance and operation, the assignment and utilization of facilities, and the administrative services for the FM organization. This is because facilities management in higher education is a triad of functional domains of 'Planning / Design & Construction', 'Operations & Maintenance', and 'Space Management' regardless of whether the institution is public or private (APPA 1997). Planning / Design & Construction domain includes two functional area of the planning and acquisition and the design and construction. The maintenance and operations functional area belongs to Operations & Maintenance domain. The assignment and utilization of facilities and the administrative services functional areas fit in Space Management domain.

3.2. Benefits of BIM-FM

BIM-FM is beneficial for not only acquiring initial data from BIM to FM information systems, but also for supporting and improving other functions of FM with its visualization and analysis capabilities (Becerik-Gerber et al. 2011). Benefits of BIM-FM that have been identified in literature are found in Table 4. In addition, 3D digital representation of building systems and analysis capabilities of BIM support other functions of FM (Becerik-Gerber et al. 2011). Multiple studies from both academic and industrial institutions address benefits from BIM integrated FM (BIM-FM), applicable areas, and the data requirements for BIM in order to leverage BIM during the O&M phase (Akcamete et al. 2010; Becerik-Gerber et al. 2011; CRC 2008; Sabol 2008; Teicholz 2013).

Table 4: Benefits of BIM-FM found in literature

Benefits	Literature				
	Akcamete et al. 2010	Becerik-Gerber et al. 2011	CRC 2008	Sabol 2008	Teicholz 2013
Capture and transfer facility information	X	X		X	X
Check maintainability		X			
Enable easy design analysis and simulation on facility				X	
Enable faster and more efficient information sharing and reusing	X	X	X	X	X
Enable visual aided marketing		X			
Help controlling and monitoring energy		X			
Help emergency management		X			X
Help personnel training and development		X			
Help proactive maintenance and repair	X	X			X
Identify patterns of breakdown/repairs	X				
Improve maintenance data management			X		X
Locate building components		X			
Provide integrated views across all facility systems	X		X		
Provide reliable facility information data base	X		X		X
Reduce equipment failures that cause emergency repairs and impact tenants					X
Support maintenance planning	X	X		X	X
Support space management	X				

In order to confirm that BIM-FM is worth implementing at higher education institutions, the researcher conducted cross-matching between the discovered benefits of BIM-FM in Table 4 and the functions of higher education institutions, described in Figure 6. In Table 5, the discovered benefits of BIM-FM are arranged in rows, and the functions of facility management department in higher education institutions are arranged in columns. Benefits that improve certain functions of facility management in higher education institutions are marked with "X". As a result, the researcher confirmed that BIM-FM supported a lot of functions of the FM department in higher education institutions, and that BIM-FM is potentially beneficial to these institutions.

Table 5: Benefits of BIM-FM marked with related functions of FM department in higher education institutions

	Functions of FM department in higher education institutions																												
Benefits of BIM-FM found in literature	Administration Services	Cost Accounting & Budget	Personnel & Training	Information Systems	Work Reception	Planning & Estimating	Maintenance Inspection Program	Work Assignment	Maintenance Service Contracting	Master Planning	Space Management	Capital Program Planning	Real Estate Management	Architect & Engineer Services	Construction Management	Renovation & Alternations	Plant Operations	Distribution	Energy Management	Control Systems	HVAC	Tele-Data	Preventive Maintenance	FM Maintenance Trades	Outside Grounds Maintenance	Waste Management	Snow Removal	Transportation Maintenance	Transportation Operations
Capture and transfer facility information				**X**	**X**		**X**	**X**	**X**		**X**						**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Check maintainability				**X**			**X**		**X**								**X**	**X**			**X**	**X**	**X**		**X**	**X**	**X**	**X**	
Enable easy design analysis and simulation on facility												**X**	**X**	**X**	**X**	**X**													
Enable faster and more efficient information sharing and reusing				**X**	**X**	**X**	**X**	**X**	**X**								**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Enable visual aided marketing	**X**	**X**				**X**																							
Help controlling and monitoring energy																	**X**	**X**	**X**	**X**									
Help emergency management																	**X**	**X**	**X**										
Help personnel training and development			**X**																										
Help proactive maintenance and repair																							**X**						
Identify patterns of breakdown/repairs																	**X**	**X**		**X**	**X**	**X**		**X**					
Improve maintenance data management				**X**			**X**		**X**							**X**							**X**						
Locate building components										**X**	**X**	**X**	**X**			**X**				**X**	**X**		**X**	**X**					
Provide integrated views across all facility systems														**X**	**X**	**X**													
Provide reliable facility information data base				**X**			**X**		**X**		**X**						**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Reduce equipment failures that cause emergency repairs and impact tenants																							**X**						
Support maintenance planning				**X**			**X**		**X**								**X**	**X**	**X**	**X**	**X**	**X**	**X**		**X**			**X**	
Support space management											**X**																		

3.3. Barriers to BIM-FM implementation

Despite the existence of technologies which support BIM-FM, demonstrated benefits from academic research and case studies, and guidelines from various organizations, the use of BIM is still largely limited to the design and construction phase but not used during the O&M phase in many projects. The disconnection in BIM data flow between the construction and post-construction phase acts as a waste in both process and product, especially when BIM contains useful operational information.

Multiple studies cover challenges in BIM-FM implementation. Akcamete and coauthors point out the difficulties in creating and maintaining complete information with the latest updates (Akcamete et al. 2010). Becerik-Gerber and coauthors also listed various challenges in BIM-FM implementation according to three categories: technological, process related, and organizational (Becerik-Gerber et al. 2011). Forns-Samso stated, "Reluctance to process change, lack of knowledge, and lack of documented metrics have prevented owners from adopting BIM to support O&M" (Forns-Samso 2010). The study also identified other barriers to BIM-FM such as lack of software interoperability, resistance to fundamental change by institutions, lack of objectives, and lack of scientific studies that quantify the value of BIM for FM. Liu and Issa indicate that the lack of knowledge of BIM among facility managers hinders leveraging BIM throughout a project's life cycle (Liu and Issa 2013). In addition, they insist on the clarification of FM's need in order to help seamless information delivery from BIM to FM database (ibid.). Sabol claims that data formats, vocabularies, and data exchange policies should be matured to develop a useful application (Sabol 2008). The barriers found in literature are summarized in Table 6.

Table 6: Barriers in BIM-FM implementation found in literature

Barriers	Literature				
	Akcamete et al. 2010	Becerik-Gerber et al. 2011	Forns-Samso 2010	Liu and Issa 2013	Sabol 2008
Cultural barriers toward adopting new technology		X	X		
Difficulties in creating and maintaining a complete database	X				
Immaturity of BIM for FM			X		
Lack of cases of positive return of investment		X	X		
Lack of cooperation between stakeholders		X	X		
Lack of legal framework		X	X		
Lack of objectives		X	X		
Lack of resources			X		
Lack of standards and processes			X		X
Lack of understanding and knowledge			X	X	
Organization-wide resistance		X			
Software interoperability issue	X	X	X	X	X
Unclear roles and responsibilities for loading data into the model or databases and maintaining them		X			
Undefined fee structures for additional scope		X			

Becerik-Gerber and coauthors classified barriers of BIM-FM implementation into three categories: technological, process related, and organizational (Becerik-Gerber et al. 2011). Technological barriers included interoperability issues between software from different vendors due to lack of common interest. Process related barriers included subjects of an act (stakeholders), their duty (responsibilities), and when they are engaged (time). Unclear roles and responsibilities for loading data into a model or a database and maintaining them, and lack of effective collaboration between project stakeholders for modeling and model utilization were the examples of process related barriers. Organizational barriers involved cultural barriers of organizations towards new technology and lack of appropriate contractual and legal structures. High software acquisition cost for owners and facility managers also acted as an organizational barrier.

In order to establish the current status on research about barriers of BIM-FM implementation, a gap analysis of the literature was conducted.

Table 7 classifies the barriers found from literature by their types. Each study is marked if there is any mention of the corresponding barrier.

Table 7: Gap analysis on barriers in adopting BIM-FM found in literature

Research	Technological barriers	Process related barriers	Organizational barriers
Akcamete et al. 2010	X		
Becerik-Gerber et al. 2011	X	X	X
Forn-Samso 2010	X	X	X
Liu and Issa 2013	X		
Sabol 2008	X	X	

Research to date on barriers in BIM-FM implementation turned out to be mainly focused on technological barriers. Issue of interoperability among different BIM software can be solved with the use of IFC. COBie supports interoperability between BIM software and FM information systems and enables automatic data transfer between them. However, research on interoperability among FM information software is difficult to solve since it requires an agreement between different software vendors which could be difficult to achieve because of competition between vendors. Though it is difficult to transfer data from one FM information system to another directly, raw data stored in BIM can travel among different FM information systems in theory. It may not be the optimal solution for interoperability issues between different FM information software from different vendors, but it nevertheless dramatically reduces time for entering data to multiple FM information software.

Unlike technological barriers, relatively smaller bodies of research on process-related and organizational barriers about BIM-FM implementation were found. Guidelines regarding the implementation of BIM-FM can help FM organizations to prepare for allocation of resources for the changed process due to the BIM-FM implementation.

It is difficult to find research about efficacy of guidelines on BIM-FM, but easy in the field of clinical science. Research suggests that although guidelines by their definition are regarded as 'desirable', they cannot be optimal for all the cases (Stevenson 2010; Woolf et al. 1999). In addition, guidelines should be updated regularly, or the dependability of the guideline as a reliable reference will be harmed (Vernooij et al. 2014). Most of the guidelines about BIM-FM have not yet been updated with lessons learned from case studies. A significant gap exists in the body of knowledge regarding how process guidelines can be used to increase adoption and effectiveness of BIM-integrated FM across multiple institutions, particularly public higher education institutions.

In all, despite the demonstrated benefits, utilization of BIM-FM is still low due to technical, process related, and organizational barriers. Research on barriers of BIM-FM implementation is concentrated more on technical barriers than on process-related or organizational barriers. Guidelines about BIM-FM implementation can help FM organizations overcome the process-related barriers by suggesting desirable resource allocation. However, guidelines should not be interpreted as optimal solution for every circumstance, and applying guidelines should be cautious according to various conditions. Furthermore, they need to be updated with lessons learned from actual practices in order to maintain their validity. The actual role of guidelines in facilitating effective BIM-FM adoption remains to be studied, including how guidelines are actually used in practice and how that use influences the success of BIM-FM for an organization.

Therefore, there are needs to understand and diagnose actual practices of BIM-FM in FM organizations to establish the current status of practice for BIM data flow.

4. Research Goal, Objectives, and Scope

Literature review revealed the need to understand and diagnose current practices of BIM-FM in FM organizations.

This chapter contains the problem statement, the goal of the research, and the objectives necessary to accomplish the research goal. In addition, definitions of terms that limit the scope of this research are described.

4.1. Problem statement

The first yet most decisive step of implementing BIM-FM is to define the types of data and their formats embedded in BIM (Liu and Issa 2013). BIM component data requirements ought to be defined at the early phase of a project to collect correct data at right time during the design and construction phase (Teicholz 2013). Well defined BIM component data requirements enable the creation of useful and quality BIM delivered to FM personnel at the project turnover phase. This allows successful data transfer between BIM and FM information systems, which lowers the cost and saves the time required for the manual input of initial data to FM information systems. Conversely, failure in defining proper BIM component data requirements results in unsatisfying experiences in utilizing BIM during the O&M phase with negative confirmation, thus increasing the likelihood of discontinuance.

However, although there are multiple prescriptive guidelines regarding data requirements for BIM-FM implementation, few organizations have comprehensively embraced it regardless of their types (Becerik-Gerber et al 2011; Jawadekar 2012; Teicholz 2013). Even among some FM organizations that have BIM component data requirements as a part of their design and construction standard, few leverage BIM during the O&M phase. There is a disconnection between how guidelines recommend preparing BIM for the O&M phase and how it is actually formed and used in practice.

Therefore it is important to understand the differences in BIM component data requirements in prescriptive representations versus actual practices at public higher education institutions.

4.2. Research Goal and Objectives

This research attempts to answer the research question of "What are the differences in BIM component data requirements between prescriptive representations and actual practices at public higher education institutions?" Therefore, the goal of this research is to compare the BIM component data requirements described in prescriptive representations (guidelines) to the one of actual practices to identify any gaps in implementing BIM-FM at the project turnover phase in public higher education institutions. In order to do this, the following objectives are established:

- To synthesize BIM component data requirements in prescriptive representations for successful BIM-FM implementation using multiple guidelines
- To diagnose BIM component data flow in actual practices using case studies of public higher education institutions
    - To investigate BIM component data requirements to designers and contractors at the early stage of the project
    - To understand the quality of BIM model and embedded component data delivered to owners and facility managers at the project turnover phase
    - To examine the use of submitted BIM model and embedded component data during the O&M phase
- To identify key differences in BIM component data requirements between prescriptive representations and actual practices.

4.2. Scope

The scope of this research is defined to specify the term BIM integrated FM (BIM-FM), guidelines as prescriptive representations, and the type of FM organizations on which the research focuses.

In this research, BIM-FM is defined as a continuous process of managing a facility with the integration of BIM and FM information systems through open formats such as IFC and COBie. BIM-FM utilizes BIM as a building database which contains a history of the facility's management and updated information.

As a representation of prescriptive BIM-FM implementation, this research uses guidelines from different organizations. According to Oxford dictionary of English, guidelines are defined as "a general rule, principle, or piece of advice" (Stevenson 2010), so it seems reasonable to regard a guideline as a prescriptive representation. Since BIM-FM requires open formats such as IFC and COBie to facilitate the turnover of operational data from the construction phase to the O&M phase, guidelines that contain discussions of BIM-FM using open formats are the only ones included in this research.

The subjects of this research are limited to public higher education institutions. As discussed earlier in section 2.1, public higher education institutions are valuable research subjects. In addition, the existing studies have focused on this area (Becerik-Gerber et al. 2011; Jawadekar 2012). 53% of respondents to a survey conducted by Becerik-Gerber et al. were from educational organizations. Jawadekar conducted a case study on Texas A&M, which is a higher educational institution. This research only focuses on FM organizations in public higher education institutions that demand BIM for new construction projects as a part of their design and construction standards. It is because new construction provides the best opportunity to experiment a full integration of BIM to FM (GSA 2011).

In short, this research is parts. First, this research reviewed suggested BIM component data requirements in guidelines. Second, current practice regarding BIM component requirements and perceived quality of delivered BIM to owners and facility managers and its usage in FM organizations at public higher education institutions were investigated. Finally the research identified any differences between prescriptive representations and actual practices in BIM component data requirements.

5. Methodology

This chapter discusses the hypothesis to be addressed by the research question, methods that yield results for analysis to reach a conclusion and test the hypothesis, identification of a study population that fits the scope of the research, and data collection and validation.

5.1. Hypothesis

In order to answer the research question of "What are the differences in BIM component data requirements between prescriptive representations and actual practices at public higher education institutions", this exploratory research tested the following hypothesis: "There would be some differences in BIM component data requirements between prescriptive representations and actual practices". This hypothesis had an underlying assumption that prescriptive representations suggested desirable BIM component data requirements for successful BIM-FM implementation and provided certain considerations of which users ought to be aware. This suggested disconnection between prescriptive representations and actual practices may prevent FM organizations at public higher education institutions from achieving successful BIM-FM implementation and result in negative experience that reduce the likelihood of continued adoption.

5.2. Methods

This research compared BIM component data requirements between prescriptive representations and actual practices to identify key differences that may prevent successful BIM-FM implementation. In order to do this, the following questions were answered:

> **Question 1:** What are the prescriptive BIM component data requirements for BIM-FM implementation?
> **Question 2:** What are the BIM component data requirements found in actual practices?
> **Question 3:** What are the key differences between BIM component data requirements in prescriptive representations versus actual practices?

To answer these questions, document analysis and case studies were performed. Two methods of observation were used for the case studies: document analysis and in-person interviews.

Among multiple types of interviews, the researcher conducted in-person interview because of two reasons. First, in-person interviews enable interviewer to catch non-verbal communication cues that could be missed during phone or e-mail interviews. Non-verbal communication cues aid not only understanding of interviewers' complex questions but also in-depth interpretations of interviewee's' responses (Opdenakker 2006). Second, in-person interview can be an effective way of reaching people when an interviewer does not have sufficient information (The Wallace Foundation 2014). In this exploratory research, the researcher attempted to conduct interviews with someone who is responsible for managing models and FM database. However, due to the complexity and diversity of the structure of FM organizations included in the study, each case study institution has titles for individuals that have similar roles and responsibilities. An in-person interview was expected to help guide the researcher to find the correct individual(s) to interview.

The purpose of in-person interviews was to address the quality of submitted BIM at the project turnover phase and the usage of BIM during the O&M phase. Therefore, major variables were BIM component data requirements shown in the guidelines and the institutions' design and construction standards. Table 8 explains the research methods to answer the research questions, along with required resources, inputs, and expected outcomes.

Table 8: Summary of addressed questions, research methods, and required resources

Question #	Research Methods	Required Resources	Input	Expected Outcomes
1	• Document analysis	• BIM guidelines • Document analyzing skill	• BIM Guidelines	• Synthesized BIM component data requirements
2	• Case study by document analysis	• Organizations • BIM component data requirements from the organization	• Design and construction standard of the organizations	• BIM component data requirements of the organizations
	• Case study by in-person interviews	• A recorder • IRB training and approval	• In-person Interviews	• Level of compliance with the BIM component data requirements • The usage of BIM during the O&M phase
3	• Direct comparison	• BIM component data requirements from the guidelines and the case study organizations	• Outcome of prior questions	• Identified key differences in BIM component data requirements between the guidelines and the case study organizations

1. The first question was solved by analyzing multiple guidelines to make a synthesis of BIM component data requirements. BIM guidelines and document analysis skills were required. From BIM guidelines, BIM component data requirements were harvested and organized by the type of information. As a result of this part, a comprehensive set of prescriptive BIM component data requirements was created and reviewed by currently practicing FM experts for validation.

2. The second question was addressed by developing case studies, including documents analysis and in-person interviews. In order to do this, organizations, BIM data requirements of the organizations, interview devices like a recorder, and IRB training and approval were required. To investigate BIM component data requirements in current FM organizations, the researcher analyzed documents which contain each organization's BIM requirements for new construction as represented in design and construction guidelines/standards. From these documents, BIM component data requirements of the organizations were derived. The goal of conducting in-person interviews was to understand how much the submitted BIM at the project turnover phase complies with the BIM requirements and determine the extent of usage of BIM during the O&M phase. Furthermore, the in-person interviews helped identify perceived challenges and barriers to implementing BIM-FM.

3. The third question was answered by comparing the BIM component data requirements from the prior two phases of research. By comparing BIM component data requirements from the guidelines and the case studies, this research identified the key differences that may act as barriers to implementing BIM-FM.

In short, this research had three phases. Phase 1 was to create a synthesis of prescriptive BIM component data requirements by document analysis. Phase 2 was to diagnose the current practices in FM organizations and consisted of two parts: to investigate BIM requirements in the organizations by document analysis, and to understand the quality of delivered BIM and the usage during the O&M phase by in-person interviews. Phase 3 was to identify the key differences in BIM component data requirements between the guidelines and the organizations.

5.3. Study population and case study selection

This research examined written guidelines as representations of prescriptive BIM component data requirements for BIM-FM implementation and conducted case studies on actual practices in public higher education institutions.

In Phase 1, the theoretical population to examine prescriptive representations of desirable BIM-FM was BIM guidelines from various organizations, and there were three elements to be considered in the population of interest. Due to the differences in construction regulations and contract structures between different countries, the study was limited to guidelines from U.S. organizations. There are some BIM guidelines from federal, state, academic, and private sources for BIM implementation (often referred to as BIM Execution Plan), and the number of guidelines keeps increasing due to increasing demand (Teiholz 2013). However, unlike limited utilization of BIM for the design and construction phase, leveraging BIM during O&M phase requires open formats such as IFC and COBie that enable seamless data transfer between the construction phase and the O&M phase. In addition, restricted guidelines used by private parties were excluded from this research because they did not act as desirable suggestions due to the limited access. Therefore, the three elements to be considered in the population of interest are: (1) to be BIM guidelines created by U.S. organizations; (2) to have discussions of BIM-FM using open formats; and (3) to be available to the public.

The researcher was able to find publicly available guidelines in literature and on the Internet. In his book of *BIM for Facility Managers*, Teiholz introduced the following 5 guidelines.

- BIM Planning Guide for Facility Owners from Penn State University
- GSA BIM Guide for Facility Management from General Services Administration
- LACCD BIM Standards, v3 from Los Angeles Community College District
- National BIM Standard- United States™ Version 2 from National Institute of Building Sciences (NIBS)
- Wisconsin BIM Guidelines and Standards for Architects and Engineers, v2 from State of Wisconsin

In addition, another guideline, *Building Information Modeling (BIM) Guidelines for Design Bid Build Contracts* from University of Southern California (USC), was discovered during the Internet search. Therefore, the following list of guidelines was found as the population for prescriptive representations. Guidelines that are not open to the public might not be included in this list.

- BIM Planning Guide for Facility Owners from Penn State University
- Building Information Modeling (BIM) Guidelines for Design Bid Build Contracts from University of Southern California (USC)

- GSA BIM Guide for Facility Management from General Services Administration
- LACCD BIM Standards, Version 3 from Log Angeles Community College District
- National BIM Standard- United States™ Version 2 from National Institute of Building Sciences (NIBS)
- Wisconsin BIM Guidelines and Standards for Architects and Engineers, Version 2 from State of Wisconsin

Table 9 describes the sampling frame of the guidelines. Each guideline is marked with "+" when it complies with each element of the population of interest. In the opposite case, it is marked with "-". The guidelines are numbered alphabetically according to the source. Among six guidelines, four guidelines fit to all three of the elements of the population of interest, and they were eligible to be the samples of the study population for prescriptive representations.

- BIM Planning Guide for Facility Owners version 2.0 from Penn State University
- Building Information Modeling (BIM) Guidelines from University of Southern California (USC) Capital Construction Development and Facilities Management Services
- GSA BIM Guide for Facility Management from General Services Administration.
- National BIM Standard-United States™ Version 2 from National Institute of Building Sciences

Table 9: Sampling frame of guidelines

Identification #	Source	Name	Element of the population of interest		
			Made by U.S. organizations	Discussion of open formats	Public access
1	General Services Administration	GSA BIM Guide for Facility Management	+	+	+
2	Los Angeles Community District	LACCD BIM Standards, v3	+	-	+
3	NIBS, building SMART alliance	National BIM standard-United States™ Version2	+	+	+
4	Penn State University, Computer Integrated Construction Research Program	BIM Planning Guide for Facility Owners Version 2.0	+	+	+
5	State of Wisconsin, Department of Administration Division of State Facilities	Wisconsin BIM Guidelines and Standards for Architects and Engineers, v2	+	-	+
6	USC Capital Construction Development and Facilities Management Services	Building Information Modeling (BIM) Guidelines for Design Bid Build Contracts version 1.6	+	+	+

In Phase 2, the theoretical population to examine actual practices was public higher education institutions. In order to conduct case studies to develop a descriptive understanding of actual practices in public higher education institutions, target organizations must require their designers and contractors to provide BIM. In addition, only major universities with the number of enrolled students higher than 30,000 were included in this research because BIM has lower return on investment in smaller- or medium scale organizations. Therefore, the three elements to be the population of interest were: (1) to be a public higher education institution; (2) to have BIM requirements for the new construction projects; and (3) to have number of enrolled students higher than 30,000. Due to the limited geographical access, the study population of this research was limited to public higher education institutions in the state of Virginia.

There are 15 four-year public higher education institutions in Virginia. Table 10 describes the sampling frame for the case study portion of the research. The institutions are numbered alphabetically. Among 15 institutions, three institutions fit to all of the elements of the population of interest:

- George Mason University
- Virginia Commonwealth University
- Virginia Polytechnic Institute and State University

These institutions are subject to the same regulations from the Commonwealth of Virginia, since they are public educational institutions funded by the state of Virginia. In addition, in spite of the existence of BIM requirements, documented literature about BIM-FM implementation was not found from any of the institutions. Therefore, it was expected that these organizations leveraged BIM for the design and construction but not for the O&M phase, and they were eligible to be samples of the study population of case studies.

Table 10: Sampling frame of public higher education institutions

ID #	Name	Element of the population of interest		
		Public higher education institutions	BIM requirement for const. projects	Number of enrolled students (year)
1	Christopher Newport University	Yes	N/A	4990 (2011)
2	College of William and Mary	Yes	N/A	8258 (2012)
3	George Mason University	Yes	Available	33723 (2014)
4	James Madison University	Yes	N/A	19480 (2013)
5	Longwood University	Yes	N/A	4834 (2014)
6	Norfolk State University	Yes	N/A	6021 (2014)
7	Old Dominion University	Yes	N/A	24670 (2012)
8	Radford University	Yes	N/A	9798 (2014)
9	University of Mary Washington	Yes	N/A	5203 (2010)
10	University of Virginia	Yes	Available	21238 (2013)
11	University of Virginia's College at Wise	Yes	N/A	2067 (2014)
12	Virginia Commonwealth University	Yes	Available	31163 (2014)
13	Virginia Military Institute	Yes	N/A	1664 (2012)
14	Virginia State University	Yes	N/A	5890 (2011)
15	Virginia Tech	Yes	Available	31224 (2014)

5.4. Data collection and validation

Data for all phases of the research were collected through document analysis and in-person interviews. All of the selected guidelines were open to the public and available online. BIM component data requirements were extracted from each guideline. Then, each set of BIM component data requirements from each guideline were validated through reviews from currently practicing FM experts via e-mail communications or in-person interviews which was another part of this research. After consolidating sets of BIM component data requirements from each guideline, they were compared to each other and synthesized as one compiled BIM component data requirements. As a result, a comprehensive set of BIM data requirements was created from the guidelines.

In order to recruit FM organizations for case studies, e-mails asking for the research cooperation were sent to the three samples of public higher education institutions. The e-mails described brief explanation of the research and the researcher, reasons why the institution was selected for the research, what was expected from the in-person interview, and the compensation to the participants (no compensation was provided). In addition, an interview protocol with objectives and sample questions were attached to the emails. Appendix 1 contains the interview protocol which was used in this research. After obtaining consent for participating in the research from FM staff, analysis on the design and construction standards of each organization was conducted to establish BIM component data requirements. The BIM component data requirements developed in this way were subsequently validated by the organization's FM staff via e-mail communications or at the interview.

In-person interviews were scheduled upon the interviewee's availability. During the interview, the compliance with BIM data requirements at the project turnover phase, how BIM is used or planned to be used during the O&M phase, and the interviewee's opinion on barriers to implementing BIM-FM were asked. The interviews including the verbal consent of interviewees were recorded during the interview, and the recordings were transcribed after the interviews. Then, the researcher organized and summarized the transcripts and sent them to the interviewees for validation.

The intent of this study was to compare BIM component data requirements in prescriptive representations and actual practices. BIM component data requirements were collected through document analysis on existing BIM guidelines and the design and construction standards of each case study organization. All data were validated through e-mail communications or at the interviews. Other information collected at the interviews such as the compliance with BIM data requirements at the project turnover phase and the usage of BIM during the O&M phase helped the understanding of current status of BIM flow in case study organizations.

6. Results

This chapter explains results from conducting the procedural methods described in the previous chapter. The researcher has carried out all three phases of the research to achieve results including analysis to test the established hypothesis. The result is described in three phases.

6.1. Phase 1: Synthesis of Prescriptive Guidelines

In order to create a synthesis of prescriptive BIM component data requirements, the researcher analyzed the samples of prescriptive representations. As described in section 5.3, the following guidelines were selected as samples of the prescriptive representations of BIM integrated FM (BIM-FM):

- General Services Administration (GSA): BIM Guide for Facility Management from General Services Administration
- National Institute of Building Sciences (NIBS): National BIM Standard-United States™ Version 2
- Penn State University: BIM Planning Guide for Facility Owners version 2.0
- University of Southern California (USC): Building Information Modeling (BIM) Guidelines

In this research, each guideline is represented as their source organization instead of referring full name of it. Synthesized BIM component data requirements were reviewed by industry practitioners who are experts in facility management with an average experience of 15 year via e-mail communications and at in-person interviews in phase 2.

All four selected guidelines included in the analysis are described individually in the subsections that follow.

6.1.1. General Services Administration (GSA) guideline

GSA released a guideline called "BIM Guide for Facility Management from General Services Administration" in 2011. GSA guideline is specifically designed for the one organization: GSA. Though GSA is one organization, it is the largest property owner in the U.S. with a variety of facility types. GSA manages 362 million rentable square feet in 9624 buildings in all states of the U.S. plus 6 territories. According to GSA, they are the party who "designs, constructs, operates, and manages a variety of facility types including federal office buildings, courthouses, and land ports of entry" (GSA 2011).

In order to meet the proper goal of various types of projects, the GSA guideline provides minimum requirements and suggestions, leaving the details to each project team. The document is created to be generally applicable for various types of facilities.

The GSA guideline is composed of overall vision and objectives for using BIM during FM, an implementation guide, BIM object and attribute requirements, available technologies, and on-going pilot projects.

6.1.1.1. Introduction of BIM data requirements

GSA divides the level of BIM data requirements into three tiers so that the project team can choose appropriate level to meet the purpose of the project. The following list describes the information that should be included in each tier, and each tier builds upon the previous one.

- Tier 1
  - Spatial Program BIM
  - Accurate As-Built Geometry for equipment
- Tier 2
  - Equipment information: ID, Make, Model Serial Number, Warranty information, Maintenance instructions, etc.
- Tier 3
  - As-designed BIM with energy analysis predictions

In Tier 2 or higher projects, all the equipment attribute information must be submitted. GSA does not mandate to include each attribute's information within the model, but GSA asks the required information to be submitted via COBie compliant files.

The document specifies elements to be modeled in record BIM. Record BIM is BIM model that "represent the final as-constructed building and components configuration, including Architectural Supplemental Instructions, Change Notices, and field changes" (GSA 2011). GSA requires including the following set of properties to each modeled element (object) for identification:

- The BIM object Globally Unique Identifier (GUID): the machine-interpretable unique identifier that maintains the linkage between the Facility Management Systems and BIM authoring-application. GUID are managed by the software, not users.
- The BIM object location primary key: the identifier that provides quick identification of the equipment location.
- Asset Identification Number: a unique, human-interpretable naming convention that allows for easy equipment identification by facility management in the 3D model and facility management systems.

Any BIM authoring applications can be used for the modeling, but the project teams have to be able to submit the models in industry foundation classes (IFC) formats.

6.1.1.2. BIM component data requirements

Although the GSA guideline does not mandate to include data within the model, it does ask contractors to submit COBie deliverables which can be converted into BIM component data when the information is put into associated BIM objects. Therefore, it is reasonable to consider required COBie attributes as BIM component data requirements.

For all projects that involve changes in space, zone, building systems, or equipment, COBie deliverables have to be submitted in compliance with Table 11. The COBie submittals must be identical to the same attribute data as in record BIM for all BIM objects including identifying keys.

As shown in Table 11, GSA does not demand for all worksheets of the standard COBie spreadsheet 2.4. It only requires completing attribute data in 10 worksheets. In short, the list of BIM component data requirements of the GSA guideline is same as the list of required attributes in COBie worksheets which GSA has specified in the guideline.

Table 11: COBie sheets with description and attributes required by GSA (Adapted from GSA 2011)

COBie Worksheet	Description	Required Attributes	GSA Required
Contact	Capture data providers and manufacturers contact information	E-mail, Created On, Company, Phone	Yes
Facility	Facility description and measurement standards	Name, Area Measurement	Yes
Floor	Identifies floors or levels	Name, Created On	Yes
Space	Identifies rooms or spaces	Name, Created On, Description	Yes
Zones	Identifies zones	Name, Created On	Yes
Type	Identifies equipment, parts, or materials and warranty information	Name, Created On, Description, Model Number, Warranty Duration Parts, Warranty Duration Labor, Nominal Length, Nominal Width, Nominal Height	Yes
Component	Associates building components with building systems	Name, Created On, Description, Serial Number, Installation Date, Warranty Start Date	Yes
Systems	Associates building components with building systems	Name, Created On	Yes
Job	Identifies operations and maintenance procedures	Name, Created On, Description, Duration, Start, Frequency	No
Resource	Special materials, tools or training required to complete a Job Task	Name, Created On	No
Spare	Identifies spare parts lists	Name, Created On	No
Documents	Indexes submittal documents	Name, Created On, Directory, File	Yes
Issues	Identifies other issues including operational safety issues	Name, Created On, Type, Risk, Chance, impact, Worksheet Name, Row Name, Description, Owner, Mitigation, External (System, Object, and Identifier)	No
Coordinates	Applies coordinates to a facility, floor, space or component	Name, Created On, Category, Worksheet name, Row Name, Coordinate X, Y, and Z Axis, External (System, Object, and Identifier), Clockwise Rotation, Elevation Rotation	No
Attributes	COBie2 extensibility alternative for user defined columns in other worksheets	Name, Created On, Value, Unit	Yes
Connections	Identifies logical connections between components	Name, Created On, Connection Type, Worksheet Name, Row Name, Realizing element, Port name, Description	No

6.1.2. National Institute of Building Sciences (NIBS) guideline

NIBS released a guideline called "National BIM Standard-United States™ Version 2" in 2011. The NIBS guideline strongly resembles the characteristics of a research paper. The main topics of the document include term definitions, principles and theories, conceptual needs of BIM, data transfer, and lifecycle information management. Information in the guideline is at a macro scale that cannot be applied directly to actual practices. For example, the document specifies information exchange requirements. The requirements suggest a framework which consists of a series of questions that should be answered to achieve successful information exchange. Table 12 illustrates the information exchange requirements in NIBS guideline.

Table 12: Information exchange requirements in NIBS guideline (Adapted from NIBS 2007)

Category	Question to be addressed	Example answer
Who	Who is requesting the information?	The architect is requesting a cost of the current design.
Why	Why is the activity happening?	A cost activity is needed.
When	When/at what phase is project execution?	Design development is one OnmiClass phase.
What	What defines the entities, objects, and properties of the architectural model needed by the estimator to complete the task?	No example found
	What is the expectation of what is delivered between the parties and the applications?	The estimator may need only the quantity output of the architect's model, not the model geometry.
To Whom	To whom is the request being given?	The cost estimator is asked to estimate the model.
How	How generally are the resources used to develop the design and construction of a project that do not become part of the project?	Vehicles, computer systems, scaffolding, etc.
Inputs & Output	Inputs and outcome data are referenced and utilized during the process of creating and sustaining the built environment.	No example found

As depicted in Table 12, not only does the guideline not explore further details of what kind of information is required for information exchange, but it also deals with macro scope of information exchange without specific descriptions on BIM data requirements with FM purposes. Therefore, a list of BIM component data requirements with FM purpose was not able to be generated from NIBS guideline.

6.1.3. Penn State University guideline

Penn State University released a guideline called "BIM Planning Guide for Facility Owners version 2.0" in 2013. The Penn State University guideline provides detailed procedural steps for planning BIM integration within an organization, but it does not have any types of owners or organizations on which the guideline focuses. Therefore, the document specifies instructions for owners and organizations step by step to plan and prepare BIM integrated FM. However, it is open when it comes to the applications, leaving the readers to make use of the document and decide the types of information they should put in their own BIM plan.

A short list of BIM component data requirements of a boiler example was found in a case study of Penn State office of Physical Plant. The list includes a series of identification information, location information, maintenance information, and product data. Table 13 classifies the requirements into 4 categories: identification information, location information, maintenance information, and product data.

Table 13: BIM component data of a boiler at Penn State Office of Physical Plan case study categorized by information type (Adapted from Penn State University 2013)

Required BIM component data	Information category
Identification information	Equipment ID
	Maximo Barcode #
	Type
	Sub classification (Select)
Location information	Location
Maintenance information	Installation data
	Fuel type
	Source power panel name
Product data	Boiler size
	Source Breaker Number (s)
	Manufacturer
	Maximum working pressure
	Model #
	National board number
	Safety relief pressure
	Serial #

However, the information was nothing but an example of BIM component data for a boiler, and there were no further descriptions on BIM component data requirements for other equipment or building components. In short, a list of BIM component data requirements was not found in this guideline.

6.1.4. University of Southern California (USC) guideline

USC released a guideline called "BIM Guidelines version 1.6" in 2012. The USC guideline was designed specifically to apply to USC. Since the document is designed for a specific organization for limited types of projects (dorms, laboratories, classrooms etc.), it contains a high level of detail. It is understood that the guideline acts as an example of a BIM implementation plan for a higher education institution rather than a tutorial that provides general considerations for creating a BIM implementation plan.

The USC guideline is composed of detailed descriptions of the purpose of creating models, deliverables and level of detail of the models, BIM process and modeling requirements for both design team and construction team, and specifications from the facility management group. The documents depicted tasks to be done at each stage of design development (Schematic Design, Design Development, and Construction Documents). In addition, it specifies the type of BIM application to be used and the naming conventions to ensure availability and consistency of information. All the data should be saved in "e-Builder," USC's Project Management Information Systems (PMIS) server.

Although the USC guideline provides model and data requirements, details and responsibilities to fulfill the requirements are addressed within the BIM execution plan which is delivered as a part of proposals/bid submittals by architects and general contractors. Therefore, BIM data requirements in the document provide only minimum requirements and act as a basic templet requirements where additions and exemptions are adjusted at an early phase of each project.

6.1.4.1. Introduction to BIM data requirements

BIM data requirements of the USC guideline can be divided into two types: elements to be modeled and BIM component data. Figure 7 shows the structure of BIM data requirements. The document specifies elements to be modeled by Architectural, Structural, HVAC systems, Electrical Systems, Plumbing and Fire Protection, Specialty Equipment, and Civil Engineering. BIM component data must be attached to each modeled elements (objects). Besides real building elements, the document also specifies how to model operational clearances, such as clearance zones for access, door swings, service space requirements, and gauge readings as invisible solids within the object.

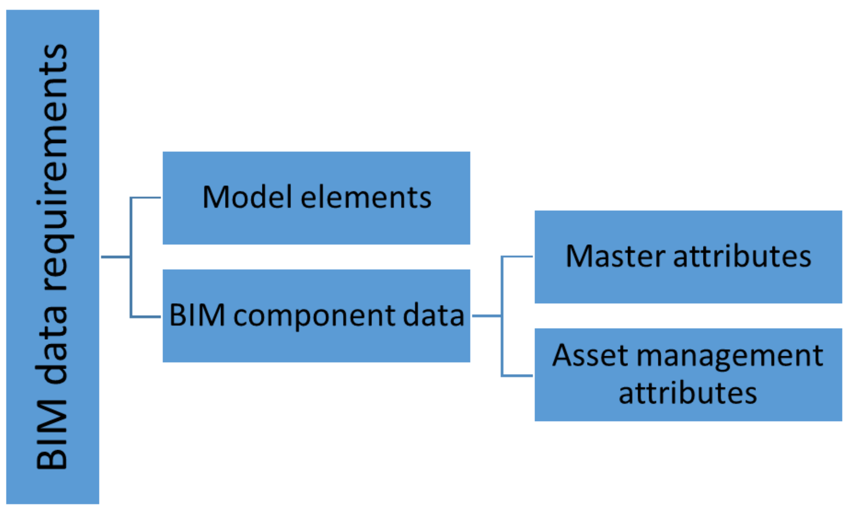


Figure 7: USC BIM data requirements structure

6.1.4.2. BIM component data

BIM component data is divided into two attributes: Master attributes and Asset management attributes. Master attributes are composed with a series of identification information. Table 14 shows elements of Master attributes and their name to be shown in parameter of each object in the model. On the other hand, Asset management attributes are the specifications and performance type data, typically found in an equipment schedule. Detailed lists of Asset management attributes are not specified in the document because they are determined at the early phase of each project and vary from project to project.

		REVIT PARAMETER NAME	Description
USC MASTER ATTRIBUTES	Obtained from USC	USC Site Code	USC Site Code Designation
		USC Building Number	USC Building Designation
		USC Floor Number	USC Floor Designation
		USC Equipment Number	USC Equipment Number
		USC EMSID	Unique Id assigned to selected pieces of USC equipment for Energy Management purposes
		Number	USC Room Number designation
		Name	USC Room Name designation
		OmniClass Number	Corresponding OmniClass XX-XX XX XX XX number
		OmniClass Title	Corresponding OmniClass description to the OmniClass number
		Uniformat Number	Corresponding product's UniFormat number
		Master Format Number	Corresponding products's Master Format number
USC NOMENCLATURE		Type Name	According to USC Nomenclature Guideline
		Type Description	According to USC Nomenclature Guideline
		Instance Name	According to USC Nomenclature Guideline
		Instance Description	According to USC Nomenclature Guideline

Table 14: USC elements of master attributes (Adapted from USC 2012)

Although detailed lists of Asset management attributes were not found in the USC guideline, USC has requirements for COBie spreadsheet which can be converted into BIM component data. Table 15 illustrates the COBie requirements of USC. Since COBie data can be turned into BIM component data, it is reasonable to consider COBie spreadsheet requirements as BIM component data requirements.

To sum up, BIM component data requirements in the USC guideline are the combination of three attributes: Master attributes that contain identification information of BIM objects, Asset management attributes which are the product data and performance type data of each BIM object, and COBie attributes of ten worksheets (Contact, Facility, Floor, Space, Zones, Types, Components, Systems, Document, and Attribute).

Table 15: COBie requirements of USC

COBie worksheet	Special note
Contact	n/a
Facility	n/a
Floor	n/a
Space	Should be classified using OmniClass and Net Area is provided
Zones	Should have categories assigned
Type	Should have Name, Category (OmniClass), Description, Asset type, Manufacturer, Model number, Warranty information (Parts, labor, and duration), Replacement cost
Component	Should have name, Description, Type, Space, Serial number, Installation data, Warranty start data, Tag number and/or barcode.
Systems	Should have Name, Category (OmniClass), Components
Document	n/a
Attributes	Should be classified using OmniClass and Net Area is provided

6.1.5. Synthesized BIM component data requirements

Each document has different purposes, targets different readers, and different applications which decide the types of information and the level of details it contains. BIM component data requirements with FM purposes can have noticeable deviations depending on many decisive factors such as types of organizations, types of construction projects, types of project delivery methods, construction and contractual regulations, and special conditions. Therefore, it is difficult to find a detailed list of BIM component data requirements from documents that do not have sufficient premises or limited conditions.

The researcher discovered different applications of different guidelines based on their purposes and target audience. After analyzing all the sample guidelines, two guidelines were diagnosed not to be appropriate for this research due to their generalities: NIBS guideline and Penn State University guideline. The synthesis of guidelines was thus based on two remaining guidelines: GSA and USC.

In order to make a list of synthesized BIM component data requirements, the researcher extracted BIM component data requirements from the GSA guideline and the USC guideline. Both of the guidelines do not provide a detailed list of BIM component data requirements. However, in terms of the fact that COBie data can be converted into BIM component data when the data is attached to the related object in BIM, COBie requirements can be understood as BIM component data requirements.

Both the GSA and USC guidelines mandate to submit a COBie file. However, they specify certain COBie worksheets to be completed rather than filling all 18 worksheets of COBie spreadsheet 2.4. The selection of the COBie worksheets turned out to be identical between the GSA and USC guidelines. Table 16 shows a list of attributes in selected COBie worksheets. Information on the attributes, which is a part of BIM component data requirements, should be submitted by general contractors.

Like the GSA guideline demands for certain information (BIM object GUID, BIM object location primary key, and Asset identification number), the USC guideline also mandates to include identification key in the model (Master attributes) for asset identification. In addition, requirements for equipment information like specifications were found from both guidelines.

As a result, BIM component data requirements from the guidelines can be divided into three types of information: identification system, equipment information, and selected 10 COBie worksheets. Table 17 describes BIM component data found is GSA and USC guidelines. Therefore, the researcher concluded that the synthesized BIM component data requirements from samples of prescriptive representation include identification system, equipment information, and the attributes of 10 COBie worksheets described in Table 16.

Table 16: Synthesized BIM component data sorted by related COBie worksheet

Contact	Facility	Floor	Space	Zone	Type		Component	System	Document	Attribute
• Email • Created By • Created On • Category • Company • Phone • External System • External Object • External Identifier • Department • Organization Code • Given Name • Family Name • Street • Postal Box • Town • State Region • Postal Code • Country	• Name • Created By • Created On • Category • Project Name • Site Name • Linear Units • Area Units • Volume Units • Currency Unit • Area Measurement • External System • External Project Object • External Project Identifier • External Site Object • External Site Identifier • External Facility Object • External Facility Identifier • Description • Project Description • Site Description • Phase	• Name • Created By • Created On • Category • Ext System • Ext Object • Ext Identifier • Description • Elevation • Height	• Name • Created By • Created On • Category • Floor Name • Description • Ext System • Ext Object • Ext Identifier • Room Tag • Usable Height • Gross Area • Net Area	• Name • Created By • Created On • Category • Space Names • Ext System • Ext Object • Ext Identifier • Description	• Name • Created By • Created On • Category • Description • Asset Type • Manufacturer • Model Number • Warranty Guarantor Parts • Warranty Duration Parts • Warranty Guarantor Labor • Warranty Duration Labor • Warranty Duration Unit • Ext System • Ext Object • Ext Identifier • Replacement Cost • Expected Life • Duration Unit • Warranty Description • Nominal Length • Nominal Width	• Nominal Height • Model Reference • Shape • Size • Color • Finish • Grade • Material • Constituents • Features • Accessibility Performance • Code Performance • Sustainability Performance	• Name • Created By • Created On • Type Name • Space • Description • Ext System • Ext Object • Ext Identifier • Serial Number • Installation Date • Warranty Start Date • Tag Number • Bar Code • Asset Identifier	• Name • Created By • Created On • Category • Component Names • Ext System • Ext Object • Ext Identifier • Description	• Name • Created By • Created On • Category • Approval By • Stage • Sheet Name • Row Name • Directory • File • Ext System • Ext Object • Ext Identifier • Description • Reference	• Name • Created By • Created On • Category • Sheet Name • Row Name • Value • Unit • Ext System • Ext Object • Ext Identifier • Description • Allowed Values

Table 17: COBie requirements of USC

Category	GSA	USC
Identification Info	• BIM object GUID • BIM object location primary key • Asset Identification Number	• Master Attribute
Product data	N/A	• Asset Management Attribute
COBie requirements	• 10 sheets Contact, Facility, Floor, Space, Zones, Types, Component, Systems, Documents, Attributes	

6.2. Phase 2: Determination of Actual Data Requirements in Practice

In order to investigate BIM component data requirements in actual practices at public higher education institutions, document analysis on BIM requirements of the sample institutions were conducted. In addition, in-person interviews with industry practitioners of the sample institutions were performed to diagnose the BIM data flow in the organizations. As described in section 5.3, the following organizations were selected as samples of public higher education institutions for which actual practices were identified. The documents that the researcher analyzed are identified next to each organization.

- George Mason University (GMU): Design Manual
- Virginia Commonwealth University (VCU): Building Information Modeling (BIM) Guidelines and Standards for Architects, Engineers, and Contractors
- Virginia Polytechnic Institute and State University (VT): Design and Construction Standards

6.2.1. George Mason University (GMU)

GMU is a research university which started as a branch of the University of Virginia in 1957. In 1972, GMU was separated from its parent institution and approved to be an independent four-year, degree-granting institution by the Virginia General Assembly. The university has three campuses and a satellite site; the main campus is in Fairfax County, VA, two other campuses are in Arlington, VA and Prince William Country, VA, and a satellite site is in Loudoun Country, VA.

Among several campuses of GMU, the researcher only focused on the main campus in Fairfax, VA. Fairfax Campus is located in urban area of Fairfax, VA. GMU occupies more than 160 structures 151 buildings. The total area of the campus is about 677 acres, and about 1200 pieces of equipment are regularly monitored for preventive maintenance. There are 13 schools and 208 degree-providing programs. For the 2014-2015 academic year, 33,723 students were enrolled.

GMU had a fast growth, doubling their total square footage over the last 10 years which involved about 33 new construction projects. The university has had construction projects every year since 1967, and most of its buildings were built after 1990.

GMU has variety of facilities in Fairfax campus, VA. Not limited to buildings that support academic activities such as classrooms and labs, GMU also has administrative offices, residential halls, parking surfaces, parking structures, power plants, a gym, dining facilities, a library, and concert halls.

The following subsections describe organizational structure of FM department of GMU, BIM implementation history, FM database management, GMU Design Manual, GMU BIM requirements, and GMU BIM data flow.

6.2.1.1. Organizational structure of FM department of GMU

The Facility Management Department is comprised of 7 branches at GMU (Figure 8) (George Mason University Facilities 2015). The individual interviewed by the researcher is the one who is responsible for managing enterprise systems and the one who is responsible for record management and budget analysis. An organizational structure diagram (Figure 8) and descriptions of branches' responsibilities from GMU Facility Management Department website are followed.

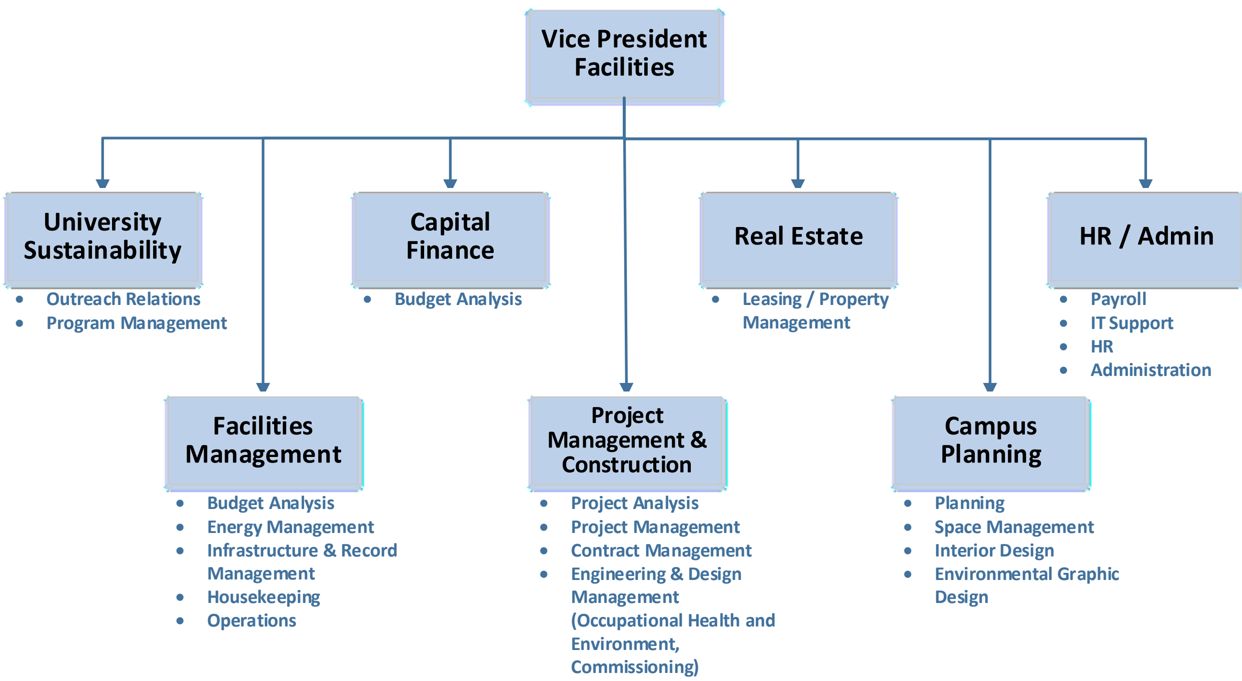


Figure 8: GMU Facility Management Department organizational chart (Adapted from George Mason University Facilities 2015)

- University Sustainability: is responsible for projects and studies intended to provide leadership in environmental, social, and economic stewardship on GMU campuses and throughout the local and global communities.
- Facilities Management: operates, cleans, maintains, repairs, replaces, renews, and secures all buildings, grounds, utilities, and other infrastructure. In addition, it includes record management and budget analysis for potential projects.
- Capital Finance: is responsible for providing budgetary oversight and financial support to the customers of University's Capital Projects. Their duties involve issuing bonds and tracking legislative funding sources, monitoring and reconciling project budgets, and facilitating the payment of invoices of the capital projects.

- Project Management & Construction: is responsible for planning, design, and construction of projects. Furthermore, it also prepares project budgets and schedules, manages construction contracts, supports construction management, takes care of commissioning, and provides services related to occupational health and environments.
- Real Estate: is responsible for overseeing overall leasing conformance.
- Campus Planning: is responsible for strategic land planning, campus master planning, long range utility planning, exterior architectural standards, landscape architectural standards, space standards and guidelines, and campus art standards.
- HR/ Admin: provides payroll, IT support, HR, and administration services.

6.2.1.2. BIM implementation history of GMU

As of the time of this study, GMU is planning to integrate their FM database with BIM, and they are at the status of conducting a case study of harvesting BIM data for FM purposes. GMU had collected some copies of BIM models before they required BIM models of their architects and contractors, because architects and contractors developed BIM models during the design and construction phase for their own operations. Needless to say, the BIM requirements were not a part of a contract, so the quality of models was different from project to project. Several years ago, GMU started a BIM roadmap group in an effort to establish a comprehensive BIM plan with the consideration of utilizing BIM during not only the construction phase but also the O&M phase, integrating all of their FM databases with BIM. However, due to the frequent turnover of senior leadership, the BIM roadmap group could not intensively continue their effort. They took a step back from the big vision they had and decided to start with experimental case studies. A recent accomplishment of the BIM roadmap group was to develop RFP language that reflects facility managers' needs and concerns. This RFP was used as contractual BIM requirements in a case study which is presently ongoing. The next big plan of utilizing BIM is to migrate all the space data from CAD-based to BIM-based.

6.2.1.3. FM database management of GMU

GMU has several groups in its facility management department which have their own databases: Preventive Maintenance Group, Building Automation Group, Space Planning Group, Record Group, Ground Maintenance group, Customer Service group, and GIS group. Every group has different databases, and they are not interoperable with each other. The fractured FM database can be attributed to the rapid growth the GMU experienced. New functions and groups were added to the FM department and each added their own FM database. It is frequently observed that FM department tend to grow and restructure haphazardly as functions are added and dropped (Friday 2003). Since each database does not talk to each other, any changes made in one database are not reflected in others. To address this problem, GMU is trying to implement an integrated FM system in near future.

The database update for a new facility is completed through manual data entry. After construction is finished, a pile of documents and drawings are delivered to FM department. People from different groups in the department take each portion of delivered documents, which is related to their responsibilities, and review them. When some valuable pieces of information appear, they put them into their own database.

Most of the databases do not support functions related to BIM. Building automation system and space management system can host CAD drawings, but they cannot host BIM models like all of the systems being used by the university. In order to be able to view the models after construction, Facility Management Department is required to purchase licenses for BIM software.

6.2.1.4. GMU Design Manual

GMU released "GMU Design Manual" on June 28, 2013. It is open to the public and available to be downloaded on the Internet. The Design Manual is intended to inform and direct project teams for any new construction, renovation, or alteration of facilities or spaces at GMU. The document contains procedures and standards for construction projects, preferences on certain materials to be used in the construction of facilities, and answers to common questions related to construction projects.

6.2.1.5. GMU BIM requirements

In the document, chapter 2.2 "Document Organization and Format" contains some BIM requirements. GMU demands the use of BIM on all new capital outlay building projects and select renovation or infrastructure projects. In addition, COBie format file requirements for the database formation are also mandatory. GMU also encourages the design team to form a BIM Implementation Team and to develop and follow a BIM Execution Plan.

However, the document does not specify detailed requirements for BIM. It mentions to follow National BIM Standard and COBie, but it does not lead to further explanation. Since the university uses Revit as its BIM software package, it encourages the use of the same BIM application. Also, GMU requires that electronic drawing files must be in a format no older than two versions before the latest release.

The researcher also reviewed a contract of a dormitory project. GMU is conducting an internal case study on the dormitory project. The purpose of the case study is to test the feasibility and benefits of harvesting data from BIM for FM purposes when comprehensive development of request for proposal (RFP) documents was provided to the project participants at the early phase of the project. The BIM requirements on the project specify the BIM software/application to use, the ownership of the models, components to be modeled, Quality Control as a data validation plan, and COBie requirements.

While the document provides a detailed list of elements to be modeled for the project, it does not contain much information of BIM component data. Although the document has BIM component data requirements called "Facility Data," it does not give further explanation on which data should be prepared. Furthermore, the purpose of specifying the BIM component data requirements is to improve the delivery of facility design intent, not for the usage during O&M phase. In short, the BIM requirements of GMU are focused on more the definition of BIM objects to be modeled than the BIM component data requirements.

Therefore, along with COBie requirements specified in the GMU Design Manual, BIM component data requirements of GMU involve two aspects: COBie spreadsheet and some Facility Data which encompasses material definitions, qualities, and attributes that are essential for the project facility design.

The reason the Design Manual does not contain detailed BIM data requirements is that GMU is at the early stage of developing general contractual BIM data requirements. GMU is conducting a case study on leveraging BIM throughout the facilities life cycle, and they have developed BIM data requirements for a specific project but not in general to apply across all projects. The next section explains BIM data requirements that were found in the case study project.

6.2.1.6. GMU BIM data flow

Although GMU is collecting BIM models with plans of integrating them with their FM database, currently BIM is not directly used during O&M phase. GMU is in the process of testing the benefits of BIM during O&M phase by conducting a case study where a detailed RFP containing a special FM platform delivery requirement was included. GMU is codifying their FM needs and turning them into contractual terms in order to leverage BIM during O&M phase in the future. However, BIM is not currently used after construction is completed.

For the case study project, detailed BIM requirements, which contain a list of objects to be modeled, were published as a part of the RFP. In addition, there was an additional contractually required deliverable as a part of the endeavor to leverage BIM for FM. This deliverable is called Simple FM. It is a FM platform which has various schedules organized by categories. The schedules provide construction information and hyperlinks which are linked to related construction documents, so that the building users and facility managers can easily find necessary information. The information in Simple FM can be harvested directly from the BIM model which was generated during the design and construction project.

The project is in its last phase of construction, and thus the demonstration of the platform has not been performed yet. The construction team has successfully completed harvesting data from BIM, and they are organizing them. The facility has not been turned over to facility managers, yet. Figure 9 illustrates the BIM data flow in the case study.

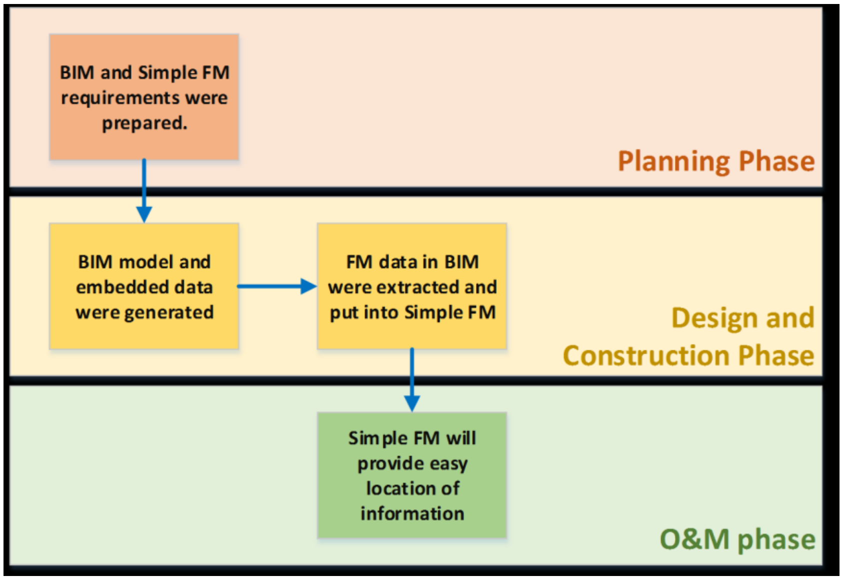


Figure 9: BIM data flow in a GMU project

6.2.2. Virginia Commonwealth University (VCU)

VCU is a research university founded in 1838 as a medical department of Hampden-Sydney College. In 1844, the main building, Egyptian Building, was constructed, and it is the oldest building at VCU. VCU became an independent higher education institution in 1854 and a state-funded college in 1860. VCU has multiple branch campuses and satellite locations: the main campuses are in the downtown area of Richmond, VA; a research part and a medical center are in other locations of Richmond, VA; the Inova campus for school of medicine and pharmacy is in Falls Church, VA; and a branch campus of school of art is in Qatar.

Among several campuses of VCU, the researcher only focused on the two main campuses located in the urban area of Richmond, VA: Monroe Park Campus and MCV campus. VCU owns 144 acres in downtown Richmond and more than 200 buildings. There are 13 schools and one college offering more than 200 degree or certificate programs. In the 2013-2014 academic year, 31,163 students were enrolled.

Since the university has a long history and a steady growth, facilities of VCU are distributed over the downtown Richmond area including many historical buildings. VCU has 54 historical buildings, and 40 buildings were constructed prior to 1900.

VCU has variety of facilities in the two main campuses in Richmond, VA. Not only buildings that support academic activities such as classrooms and labs, VCU also has administrative offices, residential halls, hospitals/medical centers, parking surfaces, parking structures, a power plant, gyms, dining facilities, library, and concert halls.

The following subsections describe organizational structure of FM department of VCU, BIM implementation history, FM database management, VCU Building Information Modeling Guidelines and Standard, VCU BIM requirements, and VCU BIM data flow.

6.2.2.1. Organizational Structure of FM department of VCU

VCU's Facility Management Department is comprised of 8 branches (See Figure 10) (Talor 2014). The individuals whom the researcher interviewed are the one responsible for space management and the one responsible for project management for capital projects. An organizational structure diagram (Figure 10) and descriptions of branches' responsibilities from VCU Facility Management Department website are followed.

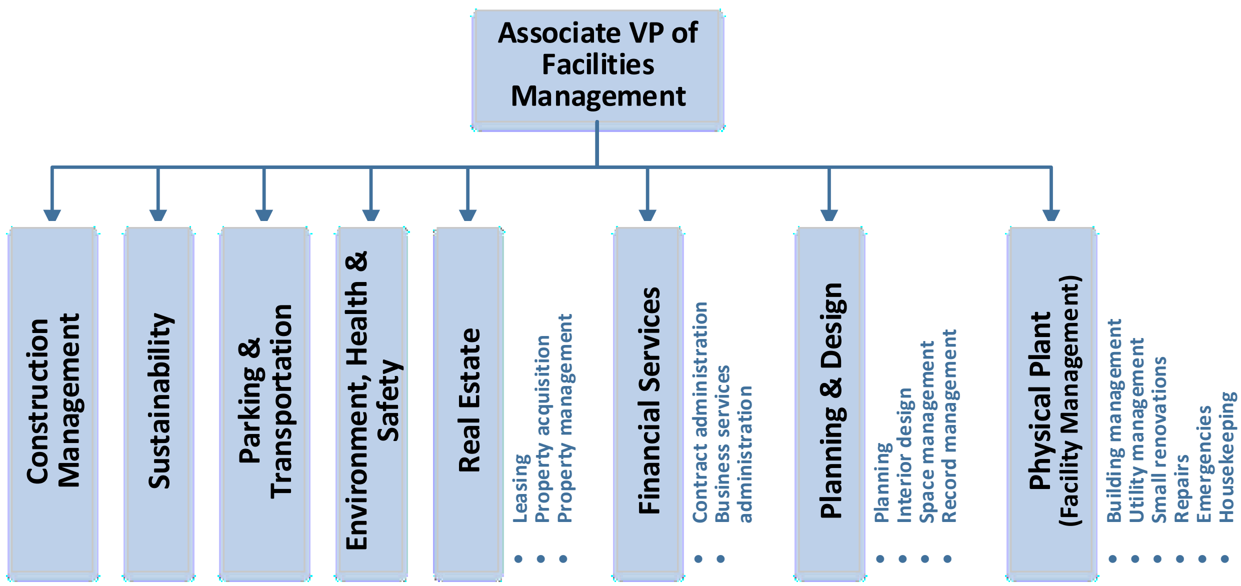


Figure 10: VCU Facility Management Department organizational chart (updated: 10/23/2014) (Adapted from Talor 2014)

- Construction Management: is responsible for project management of capital projects and renovations.
- Sustainability: supports projects to reduce emissions in all areas of campus life.
- Parking and Transportation: manages parking inventories and transportation programs.
- Environmental Health & Safety: supports a safe and healthful environment at VCU by providing surveys, consultation, teaching, advising, and environmental monitoring.
- Real Estate: provides real estate services and management such as acquisitions, leasing, property management, developing agreements for facility use, easements, collaboration on development projects, and general disposition for university and real estate foundation holdings.

- Financial Services: manages contracts and provides administrative services include human resources, payroll transaction processing, asset costing of labor and materials, utility invoice payment, and customer billing services.
- Planning & Design: supports planning and design for the university's development including evaluation of facility needs, interior design, space management, and record management.
- Physical Plant: provides workmanship to manage and maintain the university facilities. Detailed tasks involve small renovations, equipment repairs, office furniture repairs, utility management, dealing with emergencies, and housekeeping.

6.2.2.2. BIM implementation history of VCU

VCU has a short history of BIM. The use of BIM was initiated by contractors and architects before the university started to demand it by contract. In 2013, VCU started to require BIM for new constructions and released "Building information Modeling Guidelines and Standards for Architects, Engineers, and Contractors". The motivation to create such document was to define and specify their BIM requirements at the beginning of projects, so that they can get useful models at the end of the construction. The Planning & Design department worked on creating the BIM guideline in conjunction with an outsourced consultant. However, unlike the guideline which involves considerations of utilizing BIM to support various FM functions, current utilization of BIM at VCU is limited during the design and construction phases. VCU is at a stage of gathering data and BIM models but not utilizing the whole functions for facility management that BIM provides. The guideline and requirements are designed with the expectation of gathering the right building database for the future when the facility management department starts leveraging BIM. Therefore, every requirement in the guideline is not strongly enforced in current construction projects. The guideline is modified and tweaked to create the best suitable BIM requirements for each project at the early phase of a project. VCU has two construction projects where BIM was used according to the requirements from the university by March, 2015.

6.2.2.3. FM database management of VCU

VCU has different databases for each function of facility management, but they are all tied to one integrated FM management system. The system is fed by many fractured databases and publishes work orders for maintenance/repair/operations. In addition, VCU has some systems that is connected to multiple databases to create valuable data. For example, space database is connected to other databases to calculate the amount of dollars that were spent for sponsored research per square foot. Therefore, there are many FM databases which are linked to one integrated FM management system.

After construction, the data are manually collected and put into each database by hand. Only CAD drawings that the university receives for new construction are automatically transferred into the space management database. Other non-geometric data is entered manually to related databases and updated manually.

6.2.2.4. VCU Building Information Modeling Guidelines and Standards

VCU released "Building information Modeling Guidelines and Standards for Architects, Engineers, and Contractors" on 9/20/2013. It is open to the public and available to be downloaded on the Internet. It is comprised of considerations on benefits of using BIM, term definitions, description of level of detail, BIM Project Execution Plan (BIM PEP), model ownership, and BIM model element requirements.

VCU designed the document to be modified and updated by project participants at the early phase of each project to reflect project specifics. Therefore, the terms and requirements used in the document are very general. Detailed roles, responsibilities, and BIM requirements are decided at the early stage of each project when designers and general contractors submit their BIM PEP.

VCU requires energy modeling to be done by designers, which was not found in either of the other two cases in this study. However, further requirements or standards of energy modeling were not described in the document.

The purpose of the document implies that VCU does not have plans to leverage BIM during O&M phase. According to the document, its purpose is to ensure to improve design and construction services and documentation at the turnover phase. No mention on leveraging BIM during O&M phase was discovered.

When the BIM authoring software that the design team uses has interoperability with the rest of the team, any BIM authoring software can be used for the project. However, the final deliverables need to be delivered on a platform the university currently utilizes, which is Autodesk platform including Revit, Navisworks, and AutoCAD in the latest versions.

6.2.2.5. VCU BIM requirements

Since the detailed roles, responsibilities, and milestone deliverables are decided when the design team and general contractors submit their BIM PEP, BIM requirements depicted in the guideline document should not be understood as an exhaustive list of BIM data requirements.

The document devotes a lot of pages to specify elements to be modeled including geometry and physical characteristics, but a few BIM component data requirements exists. Furthermore, VCU does not demand its teams to populate building component data within the model. Equipment information such as specifications, O&M manual, and warranties should be submitted in PDF format which is compatible with neither VCU's BIM nor FM information systems.

For all of the Revit models, a spreadsheet describing all scheduled elements derived from the model must be created. Also, another spreadsheet containing the following asset data is required:

- Building number (Provided by VCU)
- Floor number (2 digits, Ex: 0B, 01, 02, 03, etc.)
- Room Numbers (Assigned by VCU through the hoteling system document)
- Room Name (Assigned through Revit Model)
- Room Use Type (Office, Conf. Room, Janitor/Customer., Classroom, Lab, Lecture, Stairs, Elevator, Lobby, Reception, Corridor, Other)
- Square Footage (Derived from Revit Record Model)

This could be understood as a part of BIM component data because the information in the spreadsheet can be converted into BIM component data like COBie does. However, besides the asset data, the other information in COBie spreadsheet, like product/equipment data, is not required. In addition, VCU does not ask for COBie spreadsheet at all.

Although the document specifies the naming convention for name of drawings and model, any identifying system or nomenclature of modeled objects were not found in the document.

6.2.2.6. VCU BIM data flow

Although VCU is requiring BIM models for all of their new construction and major renovations, VCU does not presently have plans of integrating their FM database with BIM. VCU is not directly using BIM during O&M phase but only during the design and construction phase. The usage of BIM during design and construction phase is for visualizing the design intent, construction coordination, clash detections, and improving layoff productivity using model-based surveying applications.

The reason VCU does not presently have plans to integrate BIM to their FM database has to do with the special conditions of VCU. VCU has a considerable number of existing facilities. In order to implement BIM-FM, developing BIM models for existing facilities is required. However, the cost of developing BIM models of existing facilities is very high. In addition, most of VCU's buildings were built before 1997, and some of them were constructed in late 19^{th} and early 20^{th} centuries. Some old buildings do not even have proper drawings, and BIM models should be developed based on measurements. This has higher risks of errors, so VCU does not presently see the benefit of investing in BIM-FM. It is cost prohibitive.

However, they are open to integrating their asset database with BIM for new construction. Since new construction provides the best opportunity to benefit from utilizing BIM for facility management, VCU currently plans to make use of BIM only for new construction and major renovations. Figure 11 illustrates the current BIM data flow at VCU.

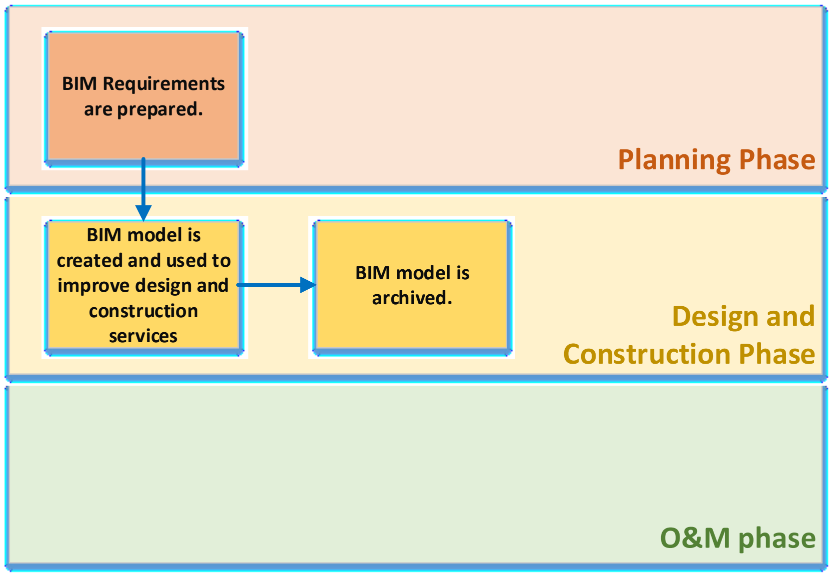


Figure 11: BIM data flow in a VCU project

6.2.3. Virginia Tech (VT)

VT is a research university. It was found in 1872 as a land-grant institution called Virginia Agricultural and Mechanical College and received sanctioned university status as Virginia Polytechnic Institute and State University in 1970. VT has a main campus in Blacksburg, VA, and off-campus educational facilities in six regions (Virginia Beach, VA, Falls Church, VA, Richmond, VA, Roanoke, VA, Abingdon, VA, and Ticino, Switzerland).

The researcher only focused on the main campus in Blacksburg, VA. The Blacksburg Campus is located in a rural area of Virginia in the town of Blacksburg, and the total area of the campus is about 2,600 acres. VT's main campus has about 135 buildings, and about 5000 pieces of equipment are regularly monitored for preventive maintenance. There are 8 colleges and 225 degree providing programs. In the 2014-2015 academic year, 31,224 students were enrolled.

VT has had continuous growth since the 1960s and has more than 10 new construction or major renovation projects in the last 10 years.

VT has variety of facilities in the main campus. Beside academic buildings including classrooms and labs, there are athletic buildings including swimming pools and a stadium, office buildings, residence halls, parking surfaces, parking structures, power plants, dining facilities, libraries, concert halls, a medical center, and memorials.

In this exploratory research, the researcher found that VT does not have official any contractual document depicting BIM data requirements. VT does ask for BIM models for new construction projects, but detailed requirements are not written in contractual documents. Therefore, the researcher could investigate neither BIM requirements nor BIM data flow of VT in detail. The following subsections describe organizational structure of FM department of VT, BIM implementation history of VT, and FM database management of VT. The researcher could obtain through online research and in-person interviews.

6.2.3.1. Organizational structure of FM department of VT

VT's Facility Management Department is comprised of 4 branches to support facility services, and an administrative service group which is under the direction of a deputy chief facility officer (See Figure 12) (Virginia Tech Facility Services 2015). The individuals whom the researcher interviewed are the one who is responsible for managing enterprise systems and the one who is responsible for project management for capital projects. An organizational structure diagram (Figure 12) and descriptions of branches' responsibilities from VT Facility Management Department website are followed.

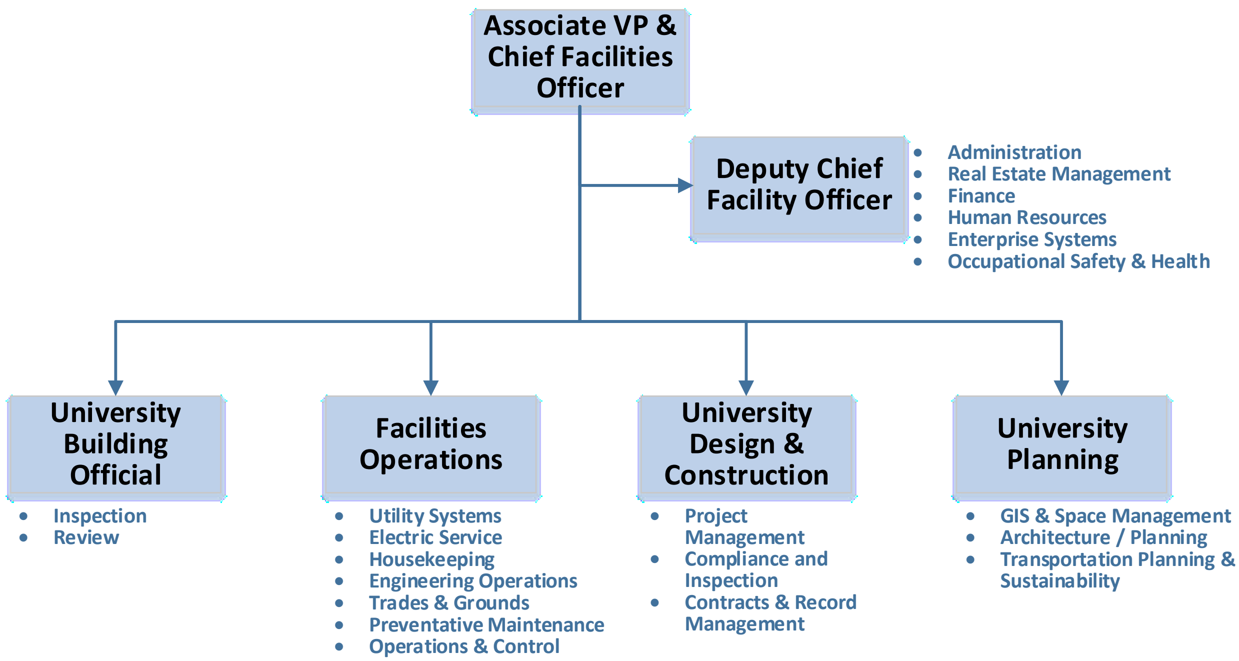


Figure 12: VT Facility Management Department organizational chart (updated: 1/8/2015) (Adapted from Virginia Tech Facility Services 2015)

- Deputy Chief Facilities Officer: directs various office support including administration, real estate management, finance, human resources, enterprise systems, and occupational safety and health.
- University Building Official: provides technical engineering and code related support.
- Facilities Operations: maintains buildings, electrical/mechanical systems, and main campus ground.
- University Design & Construction: supports project management for new construction and renovations, project finance, commissioning, and contract record management.
- University Planning: is responsible for long range planning of VT's physical environment and design specifics, managing record inventories, managing GIS data, space management, record

management, planning, GIS & Space management, transportation planning, and projects related to sustainability.

6.2.3.2. BIM implementation history of VT

VT requires their architects and engineers for capital projects to design in 3D and to turn their design model over to construction managers (CM) for use in MEP and fire systems coordination during construction. Detailed requirements are decided at the beginning of each project. However, VT presently does not have any BIM model requirements in A/E or CM contracts. Arrangements encouraging the development of models are made during the early phases of the projects. VT does receive ownership of the model at the end of construction, and the delivered model is archived. However, there currently are no contractual obligations for the A/E or CM to produce BIM models, and the contractors or designers are responsible for the accuracy of the models.

6.2.3.3. FM database management of VT

VT has an Enterprise Systems unit that manages all of its facility management databases and publishes work orders. The only documents that are not managed by the Enterprise Systems unit are record drawings and documents. The Contracts and Record Management unit archives and manages them through another database.

After a facility is handed over, facility management staff manually validate and enter as-built data to the enterprise system. First, they review the drawings and documents in the office. Then, they go out to the field and manually confirm the information that they put into the enterprise system. Since discrepancies between the submitted documents (including as-built CAD drawings) and the actual as-built conditions are discovered frequently, facility managers do not rely solely on the documents; they prefer checking with their eyes in order to be 100% sure about the information that they put into the enterprise system for downstream management.

Both GMU and VCU have BIM a few descriptions on component data requirements in their BIM requirements while VT does not have any. The next section describes a comparison of differences between guideline and practices in GMU and VCU.

6.3. Phase 3: Comparison of Differences between Guidelines and Practice

In order to identify key differences in BIM component data requirements between guidelines and actual practices, the researcher compared the synthesized BIM component data requirements (Section 6.1.5) to GMU BIM requirements (Section 6.2.1.5) and to VCU VIM requirements (Section 6.2.2.5).

Synthesized prescriptive BIM component data requirements include three aspects: the identification system, equipment data, and 10 worksheets of COBie spreadsheet. The comparison matrix was created in order to find any discrepancies between synthesized prescriptive BIM component data requirements and the BIM component data requirements of GMU and VCU. In Table 18, each organization is marked if its BIM component data requirements include associated information.

Table 18: Comparison matrix of BIM component data requirements

			GMU	VCU
Synthesized prescriptive BIM component data requirements	Identification system			
	Equipment data			
	COBie	Contact	**X**	
		Facility	**X**	
		Floor	**X**	
		Space	**X**	**X**
		Zone	**X**	
		Type	**X**	
		Component	**X**	
		System	**X**	
		Document	**X**	
		Attribute	**X**	

Neither organization has an identification system that ensures consistency of names of modeled objects. A naming convention is an essential requirement for efficient communication throughout a project.

Both organizations require certain sets of equipment data that are not considered as BIM component data. GMU demands general contractors to put Facility Data within the models. Facility data includes finish materials, quality, and attributes. However, the requirements described in GMU's BIM requirements documents were not specific enough to be regarded as a comprehensive list of data requirements. In addition, the term "Facility Data", which GMU defines, is similar to design description rather than equipment/product data. On the other hand, VCU depicts the list of equipment data to be submitted, but it is turned in as a PDF file from which the data cannot be harvested and used in the BIM environment.

GMU mandates general contractors to submit all 18 worksheets of COBie spreadsheet 2.4 whereas VCU does not ask for COBie at all. Instead, a spreadsheet with asset data is required for every construction project in VCU. Among 18 worksheets of COBie, Space worksheet includes information regarding asset management. Therefore, Space worksheet of COBie file is marked for VCU.

In conclusion, discrepancies exist in BIM component data requirements between prescriptive representations and actual practices. However, besides COBie requirements, the general level of information and detail in guidelines did not align to the BIM requirements of the organizations. For example, while BIM requirements of the organizations exclusively specified what elements to be modeled, BIM requirements from guidelines listed what systems should be modeled.

7. Findings and Conclusion

Final discoveries from the analysis of the results to test the established hypothesis are described in this chapter. In addition, this chapter concludes whether to confirm or disapprove the established hypothesis.

The established hypothesis of this research was that some differences would exist in BIM component data requirements between prescriptive representations and actual practices in public higher education institutions. This has an underlying assumption that the differences may prevent successful implementation of BIM-FM in actual practices. In order to test the hypothesis and identify the key differences, the researcher conducted document analysis and case studies.

7.1. Potential applications of the guidelines

Analysis of the four guidelines revealed that there was a spectrum of very different potential applications of the guidelines.

The guideline from General Services Administration (GSA) suggests a framework that is applicable to various types of facilities. It does not contain a highly detailed list of BIM component data to ensure the flexibility of the document, but it sets a ground rule of BIM implementation planning with facility management (FM) purposes. Therefore, it is useful when an organization with various property types establishes a BIM implementation plan at the organizational level encompassing all types of facilities.

The guideline created by National Institute of Building Science (NIBS) contains the result of in-depth research about information exchange and data transfer throughout a building's life cycle. It does not provide any list of BIM component data requirements but rather definitions of terms, related theories, and explanations of concepts. This is a useful reference for researchers who need a comprehensive understanding of the subject.

Penn State University's guideline is more like a tutorial which owners and facility managers can follow when creating the BIM implementation plan with the consideration of leveraging BIM throughout the project life cycle. It does not provide a list of BIM component data requirements but rather a to-do list for owners and facility managers so that they can establish BIM requirements by themselves. Since it does not target specific types of facilities, owners and facility managers with any types of facilities can follow the procedural instructions that the guideline suggests when making their BIM implementation plan.

The University of Southern California's (USC) BIM guideline acts as a successful example of a BIM guideline for higher educational institutions with limited types of facilities such as academic buildings, laboratories, and dormitories. It involves very detailed BIM component data requirements organized by three categories: subject of the action (who should collect the data), type of data (what kinds of information should be collected), and time when they are engaged (when the data should be collected). It is a very useful reference for higher educational institutions, especially when they make a start of BIM-FM with limited resources for making a comprehensive BIM implementation plan.

Table 19 summarizes the potential applications of each guideline.

Table 19: Potential applications of each guideline

Guidelines	GSA guideline	NIBS guideline	Penn State University's guideline	USC guideline
Potential applications	A reference for organizations with various property types when they develop a BIM implementation plan at the organizational level	A reference for researchers who need a comprehensive understanding of information exchange and data transfer	A to-do list for owners and facility managers when they establish BIM plan by themselves	An example and a very useful reference for higher educational institutions, especially when they establish BIM plan with limited resources

7.2. Perceived barriers to implementing BIM-FM found in in-person interviews

During the in-person interviews with facility management staff, it was found that perceived barriers to implementing BIM integrated FM (BIM-FM) depend on the different conditions of the organizations.

A university with rapid growth like George Mason University (GMU) had difficulties in acquiring and verifying construction documents with insufficient resources to review them. GMU had more than 25 construction projects over the last 10 years. Due to the continual start of new construction, facility management staff could not afford to review construction documents after a facility has been turned over. By the time the project managers could review construction documents, they were already undertaking their next projects, which made the reviewing process infeasible.

Moreover, frequent changes in leadership made GMU struggle to actively start implementing BIM-FM. A highly motivated group called the BIM Roadmap Group was started several years prior to the time of the study in order to find ways to utilize BIM data from a project to further downstream (FM). However, the turnover in senior leadership made this effort difficult to continue. In order to increase the likelihood of procedural success in developing a BIM plan, researchers at Computer Integrated Research Program suggests a project team set a BIM champion, a person with a strong desire to develop a BIM Plan. Without a designated leader responsible for BIM execution, it is difficult to continue to develop a comprehensive BIM plan at the organizational level (Computer Integrated Construction Research Program 2010).

In the case of Virginia Commonwealth University (VCU), the main barriers to implementing BIM-FM were the prohibitive cost of establishing BIM models for a number of existing facilities. VCU has more than 100 buildings, and most of them were constructed without the use of BIM. There are two projects where BIM was used for the design and construction phase. In order to implement BIM-FM, constructing a BIM model of an existing building is needed, but it requires a lot of resources. VCU has many facility management staff members who have managed their existing facilities for a long period of time. They have a good understanding of the existing buildings they manage, so VCU does not see the benefits of investing many additional resources to establish BIM-FM process for the entire campus.

Virginia Tech (VT) does not have plans to implement BIM-FM yet. Some maintenance staff looked into information on BIM-FM, and they decided that there were many issues yet to be resolved to implement BIM-FM in accordance with existing systems in VT. In addition, discrepancies between as-built documents and actual facilities prevent maintenance staff from fully trusting information they get from construction teams. Maintenance staff preferred confirming the information on new facilities through manual process and putting data to FM database than transferring data directly from construction documents (files) to FM database.

7.3. Conclusion

In section 6.3, some differences between the synthesized list of prescriptive BIM component data requirements and the BIM component data requirements from GMU and VCU were identified. However, it is difficult to say that the result reflects a gap between prescriptive representations and actual practices, which acts as a barrier to implementing successful BIM-FM. This problem stems from the different levels of information and details in the limited number of documents, which made it impossible to achieve meaningful results through direct comparison.

The four BIM guidelines that the researcher analyzed contain general BIM component data requirements, leaving readers to define the detailed BIM component data requirements according to their organizational needs. Except the guideline from University of Southern California (USC), all the guidelines do not have specific target readers with defined types of applicable facilities. This ensures generality and increases flexibility of the guidelines making them useful for most cases but decreases the general level of detail. The four guidelines were designed to assist defining organization's need.

On the other hand, organization-specific documents from GMU and VCU dedicate only a few pages to BIM component data requirements. The documents define target readers and applicable facilities, which makes it possible to describe highly detailed BIM requirements. However, in contrast to detailed requirements provided for objects to be modeled, detailed BIM component data requirements were not found. The absence of these detailed requirements may have occurred because both organizations are currently leveraging BIM during the design and construction phase but not the O&M phase. Physical characteristics of modeled objects are important when utilizing BIM during the design and construction phase to support tasks such as design visualization, clash detection, and construction coordination. On the other hand, BIM component data which contains intrinsic properties of the building components are valuable during the O&M phase. BIM component data requirements in the documents are designed for the future use when the organizations integrate BIM with their FM database; thus BIM component data requirements in the documents are minimal with rough details.

This study thus was unable to identify significant differences in the content of guidelines vs. organizational practices, since the level of detail in BIM component data requirements was considerable between guidelines and practice and the variation across both the population of guidelines and the population of case studies was considerable. Therefore, the researcher was unable to effectively test the hypothesis because the discovered differences are not comparable. At the exploratory level of this study, the gap in level of information and details between the guidelines and the documents of the organizations is too significant to conduct direct comparison and yield meaningful conclusions. However, given that both guidelines and practice are still at a very early stage of development for BIM, the population of both guidelines and organizations implementing BIM is likely to continue to grow, and future studies may be able to use the approach proposed here to obtain a higher-resolution comparison. Such a comparison could help enhance understanding of the role of guidelines in successful adoption of innovative practices such as BIM.

8. Contribution, Limitations and Future Research

Every study can be compared to a rock in the tower of research. By adding another rock on the top of prior research, it enriches the body of knowledge. In addition, it provides a support upon which future research can build. In this chapter, contributions of this research, limitations, and future research opportunities will be discussed.

8.1. Contribution of the research

As a result of this research, comprehensive BIM component data requirements from guidelines and BIM component data requirements of the case study organizations were created. Also, differences in BIM component data requirements between prescriptive representations and the case study institutions were identified. Furthermore, the research identified the potential applications of the guidelines and perceived barriers to implement BIM-integrated FM (BIM-FM) in the case study organizations, which vary based on the conditions of the organizations.

This research is expected to be beneficial for public higher education institutions and the construction industry with the following contributions:

- This research developed a set of comprehensive BIM component data requirements from existing guidelines, which can act as a framework for defining BIM component data. Owners and facility managers can refer to the synthesized prescriptive BIM component data requirements created in this research when they establish a BIM implementation plan.
- The potential applications identified for each guideline in this research may help owners and facility managers when they select useful guidelines for BIM-FM planning.
- This research may help the construction industry to predict what owners will require in the future and prepare for them. The construction industry has growing interest on utilizing BIM in FM for "coordinated, consistent, and computable building information knowledge management from design to construction maintenance and operation stages of a building's life cycle (Becerik-Gerber et al. 2011)". Thus, it is predictable that more and more projects would start requiring BIM as a part of their construction contracts including BIM component data. Synthesized prescriptive BIM component data requirements from this research would help construction industry to allocate their resources in anticipation of forthcoming contractual BIM component data requirements.
- Organizations with similar conditions to the case study organizations may be able to predict potential barriers in implementing BIM-FM discovered in this research and avoid potential problems by finding solutions to minimize them.
- This research attempted to identify key differences in BIM component data requirements between prescriptive representations and actual practices by conducting a direct comparison of guidelines and documents from the case study organizations. However, it turned out that the level of detail in BIM component data requirements described in guidelines do not parallel with the project requirements provided by the case study organizations to directly compare and produce meaningful findings. Therefore, this research confirms that other methodologies are required to diagnose disconnections in BIM component data requirements between prescriptive representations and actual practices.

The first step in solving a problem is to define the problem. Defining the gap between prescriptive recommendations and actual practices is the start of reducing the gap. This research provides helpful information to academia, FM organizations at public higher education institutions, and construction industry by providing opportunity to reduce the gap between the theory and the practices in implementing BIM-FM at public higher education institutions.

8.2. Limitations and future research

Due to the limited scope of this research, the research has intrinsic limitations which provide opportunities for future research.

- This research only included guidelines that are available to the public and the possibility exists that proprietary guidelines are substantially different. Proprietary guidelines were excluded from this research because they have less influence on other organizations than public guidelines due to their limited access. However, in future research it is recommended to include guidelines that are not available to the public to evaluate the differences between public and proprietary guidelines.
- Given that in-person interviews were selected for data collection in this exploratory study, the selection of case studies for actual practices was limited to public higher education institutions in Virginia due to geographical access. Therefore, these research findings on the current status of BIM-integrated FM in actual practices only apply for large public higher education institutions in the state of Virginia. It is difficult to generalize to similar organizations in different states with the findings from this research. In particular, each state has its own unique project procurement regulations, and this might affect the organizational motivation for implementing BIM-FM. Therefore, studies on public higher education institutions in different states would be beneficial for addressing the current status of BIM-FM adoption.
- In-person interviews were conducted with one or more individuals from each of the case study organizations. Although it is reasonable to assume that the statement from a professional person with experience and responsibilities represents the institution as a whole, the findings from interviews with a small number of representatives do not necessarily represent an organizational consensus. Interviews with multiple individuals from the same institution would not only verify representativeness of the interviews but also further validate each participant’s statement. It may yield a more comprehensive understanding of the organization.
- While conducting in-person interviews, the researcher discovered the different barriers to implementation of BIM-FM seem to depend on the condition of the organizations such as a frequency of new construction, when the buildings were constructed, organizational structure of facility management department, BIM implementation history, and the way how to manage FM database. Further studies on potential solutions to these barriers could be beneficial to organizations with similar conditions.

- This research was unable to test the established hypothesis because of the difference in level of detail and information in the two data sets. Future researchers may be able to avoid this issue by conducting additional pilot testing of data collection and analysis as the population of both guidelines and adopting organizations for BIM-integrated FM continues to grow. This exploratory study helps to set the stage for that research by identifying specific differences in level of detail across both guidelines and adopting organizations. The disparities identified in this work will therefore inform the design of future studies by providing key information on the types of information likely to be available.

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Appendix A. Interview protocol

Interview Objective:

- To understand the process of BIM model generation
- To understand what the BIM is used for
- To understand the perceived quality of BIM model
- To understand the process of BIM model management (after the construction)
- To understand facility documentation management after the turnover of facilities
- To understand CMMS Staff structure and get their contact information

1. Explanation of Research

2. Professional Background
    a. Background: ***can you briefly tell me your professional background? How did you engaged in facility management?***
    b. Responsibility at current organization: ***What is your responsibility at current organization? Can you explain your typical day?***

3. Organizational Text
    a. Groups that is involved in the process of loading data from BIM to FM: ***how many groups of people get involved in each tasks? Is this process have done by a person or multiple groups?***
    Contact information of each groups: ***Can you refer me to someone who are engaged in each steps?***
    b. Organizational setting (Work Environment that impacts on their communication) ***Do they have separate office or sit together?***

4. BIM model
    a. The purpose and use of model: ***What is the purpose of developing model and what do you use it for?***
    b. Data requirements for the model: ***What are the data requirements of the model? Such as properties of components in the model. Do you require contractors to put any element relevant information to the model? For example, if there`s an AC unit, BIM model can host properties of the AC units such as Cooling capacity, warranties, compressor type, and so on. Do you have this kind of model data requirement to the contractors?***
    c. BIM model use during O&M phase: ***Do you use BIM model during O&M? if so, for which tasks?***
    d. Responsibility of BIM model accuracy: ***who is responsible of checking BIM model and information embedded in it after the facility has handed over?***

5. Process of creating equipment inventories

a. Create: ***How do you create the inventory of equipment? Can you explain what happens after the turn over phase? How do you collect data to put CMMS or other FM systems?***
b. Validate: ***How do you validate the data?***
c. Who: ***Who does it?***
d. How long does it take for an equipment: ***How long does it take to put initial equipment information to CMMS?***

6. Why do you not use BIM-FM?
   a. Perceived reason for not adopting BIM-FM?
      Does [the organization] have experience integrating BIM to FM systems?
      If so, to what extent are you leveraging BIM in FM systems?
      If not, is it something [organization] have considered doing it but decided not to, or have not considered yet?
      Why have you decided not to integrate BIM to FM?

7. FM systems: CMMS
   a. Name of it, customized? ***What is the name of CMMS? And is it customized? Do you know the vendor or which software it is based on?***
   b. How does FM get training of using the software? ***How does CMMS staff get training of using the software?***
   c. What does it do?
   d. COBie compatible? ***Is the software COBie compatible?***
   e. Model viewing (ifc, revit) ***Does the software allow to view BIM model? If not, do you have license of software to view the BIM models?***

8. Scale of Main Campus
   a. SF? ***What is s.f. of the total facility you manage?***
   b. Equipment? ***How much equipment do you manage?***