USE OF BUILDING INFORMATION MODELING TECHNOLOGY IN THE INTEGRATION OF THE HANDOVER PROCESS AND FACILITIES MANAGEMENT

by

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Abstract

The operation and maintenance of a constructed facility takes place after the construction is finished. It is usually the longest phase in the lifecycle of the facility and the one that substantially contributes to its lifecycle cost. To efficiently manage the operation and maintenance of a facility, the staff in charge needs reliable and timely information to support decision making throughout the facility's lifecycle.

The use of Building Information Modeling (BIM) is gradually but steadily changing the way constructed facilities are designed and built. As a result of its use a significant amount of coordinated information is generated during this process and stored in the digital model. However, once the project is completed the owner does not necessarily receive full benefits from the model for future operation and maintenance of the facility.

This research explores the information that in the context of educational facilities has value to the owner/operator and that can be delivered at the end of the construction stage through a BIM-enabled digital handover process. It discusses the importance of the Information Delivery Manual and Model and proposes an open standard approach for the creation of a Model View Definition that combines Industry Foundation Classes (IFCs) with COBie standards or with Owner defined standards.

The research conducted an extensive literature review and an in-depth case study of an academic institution examining in the detail its current practices and needs for the handover of information, operation and maintenance and space management requirements as well as of the future needs of the facilities management department information system generated by the use of BIM technology. The proposed approach is validated in two parts. The first part is conducted through an online survey distributed to academic institutions across the nation and through selected interviews with facilities management staff in the local area. The second part creates a proof of concept by applying the proposed approach to an existing BIM model and then creates the model version for the handover.

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1 Introduction

The available stock of post-secondary education facilities in the US is an average of 224 SF per student enrolled (SCUP 2007), and according to the National Center for Educational Statistics (NCES) the projection of student's enrollment for the 2014 is 21.5 million of students (NCES 2014), this will result in around 4.8 billion of square feet of campus facilities to maintain during this year, keeping the stock of buildings and facilities workspaces in optimal conditions is a major and top priority task as it positively impacts on the productivity of the activities taking place in these spaces (Wiggins 2010).

The maintenance and operation of buildings is often the longest and most expensive stage in the project lifecycle; it accounts for about three times the construction cost (Fuller 2010). A key element for the proper operation and maintenance of buildings is to have timely and accurate information to support the decision-making; What needs to be done? How should it be done? and When? are some of the questions that must be answered with information to properly operate and maintain a facility. Most of this information is generated during the planning, design, and construction stages of the facility and is usually delivered when construction is completed in the form of printed or scanned documents (Goedart & Meadati 2008). The information contained in these packages includes the final versions of the building plans reflecting the current state of the facility called as-built drawings; specifications of the installed equipment with serial numbers, make, model etc.; operation manuals and maintenance of the systems that compose the facility; reports of inspections and checks made after the installation of the systems; reports of starting-up and shutting-down the systems of the facility; and warranties & guarantees of the systems installed in the facility.

Gathering, organizing and entering this information into the facilities management computer maintenance system for a typical building can be labor intensive and, to some extent an error-prone process with no additional value for the management of the facility (Gallaher et al 2004). Currently, the different stages of the project lifecycle have little or no integration, particularly between design and construction, which causes much of the information from the previous step to get lost and additional effort has to be done to recover it. A study made by the National Institute of Standards and Technology (NIST) estimated the efficiency losses in the U.S. capital facilities industry to have an annual cost of $ 15.8 billion dollars associated with inadequate exchange of electronic information among systems (Freeman 2009). Up to two thirds of this cost was directly related to the ongoing facility operation and maintenance to cover for items such as manual reentry of information, verification, redundancy and idle labor time.

When the facilities staff transfer this information to the systems utilized to manage it, they have to invest a lot of resources and can take up to six months to complete this task (Gallaher et al 2004). This process is essential because this information is used for planning and controlling the operation and maintenance of the facility.

Building Information Modeling (BIM) is a technology-based collaborative approach that enables different stakeholders at different phases of the life-cycle of a facility to generate, manage and share information through a 3D digital model. The use of BIM is gradually but steadily changing the way constructed facilities are designed and built. As a result of its use a significant amount of coordinated information is generated during this process and stored in the digital model. However, once the project is completed the owner does not necessarily receive full benefits from the digital model for future operation and maintenance of the facility. Current research efforts are being conducted primarily by educational institutions (Becerik et al 2012) to generate and coordinate processes to produce owner-oriented models and “As Built” models. Some of these approaches consist of ad-hoc solutions, or implemented through somewhat non-open, rigid commercial software solutions, or data specifications. The creation of Construction Operations BIM Exchange (COBie) standards is a step taken in the right direction to structure the owner’s lifecycle data requirements. However, because of the lack of standardization on how the electronic information exchange is being conducted, its integration with BIM still produces poor performance in the automation of electronic exchanges of information from one authoring tool to another, thus limiting the integration of design and construction information into the facilities management systems. In addition, there is still a mismatch between the type and amount of information that is needed by FM staffs and what is currently being delivered by the design and construction professionals.

This research explores the information that in the context of educational facilities has value to the owner/operator and that can be delivered at the end of the construction stage through a BIM-enabled digital handover process. It discusses the importance of the Information Delivery Manual and Model and proposes an open standard approach for the creation of a Model View Definition that combines Industry Foundation Classes (IFCs) with COBie standards or with Owner defined standards. As a result of owners can reap the benefits of implementing a reliable automated electronic exchange of information process that integrates in an efficient way the delivery of design and construction information for the long term operation and maintenance of the project, making the facility management process more efficient.

The research conducted an extensive literature review and an in-depth case study of an academic institution examining in the detail its current practices and needs for the handover of information, operation and maintenance and space management requirements as well as of the future needs of the facilities management department information system generated by the use of BIM technology. The proposed approach is validated in two parts. The first part validates the technical feasibility, it creates a proof of concept by applying the proposed approach to a model of a facility, using a BIM authoring tool to create the model version for the handover; the second part was done through an online survey distributed to academic institutions across the nation and selected interviews with facilities management executive staff in the local area.

1.1 Research statement

For a proper operation and maintenance of a facility, the staff in charge needs reliable information for decision making and taking actions. The availability of this information is a key element in the performance of the facility management staff. Most of this information is generated during the planning, design, and construction stages of the facility and usually delivered at the end of the construction using mainly paper based approaches, despite the use of BIM during the design/construction stages.

The current use of BIM is promising but still is unclear how to properly implement it. What information should be included and how to be delivered through the model needs to be answered. Interoperability issues are needs to be addressed in order to successfully integrate BIM into the handover process.

The focus of this research is to explore what kind of information that is useful for the owner/operator of a facility can be delivered at the end of the construction stage of a facility, through a BIM-enabled digital handover process for enhancing the operation and maintenance of the facility.

The research proposes an approach taking advantage of the current use of BIM for organizing the information to the FM staff at the end of the construction stage. The proposal includes an extension of the IFC's BIM basic handover model view definition, to standardize the handover of information packages. It simplifies the application of the extended model view definition through a series of charts and tables for the operation & maintenance and space management processes.

1.2 Research objectives

The three objectives of this research are:

- Identify the information that should be integrated into the BIM Model which will be of use for the FM staff.
- Identify the value of using BIM in the handover process.
- Develop an approach for integrating and maintaining this information available and usable by the FM staff.

1.3 Research scope

This research was focused on the universities and colleges campuses because among the owners, the schools and universities are the most advanced sector making efforts to include BIM as a part of the handover (Becerik et al 2012); includes a wide range of type of facilities, such as laboratories, classrooms, conference halls, auditoriums, parking lots and garages, dormitories, restaurants, sport centers, libraries, etc.; constitute the most advanced sector on the implementation of BIM for FM (see Figure 7); It was possible to have access to the FM department of the WPI, to conduct case studies and; the results derived could have an extended application to other type of owners with similar facilities.

2 Literature review

2.1 The facilities Management (FM) process

Now, more than ever, the workplace is important to employers. Collaboration and productivity are directly influenced by the layout of a workspace. Well-designed office spaces creates more productive and happier workforce. Efficient, pleasant, dynamic workplaces improve performance and productivity (Wiggins 2010). The workplace is evolving, nowadays it is common for some people work at home or in transit, however, they still need have access to some of the services they have in the workplace at the organization facility, such as, access to the network and information-technology resources, teleconferencing, etc.

The available stock of postsecondary education facilities in the US is an average of 224 SF per student enrolled (see table 1), and according to the National Center for Educational Statistics (NCES) the projection of student's enrollment for the 2014 is 21.5 million of students (NCES 2014), this will result in around 4.8 billion of square feet of campus facilities to maintain during this year.

Table 1 Mean NASF per Student by Space Type and Sector (SCUP 2007)

Room Use	Mean NASF / Student by Sector			
	Public 4-Year or Above	Private 4-year or Above	Public/Private 2-Year	All Institutions
100 Classrooms	13.2	19.1	9.8	13.6
200 Lab/Studio	35.1	37	14.3	32.1
300 Office	49.0	50.5	10.6	43.1
400 Study	12.4	20.6	3.8	12.4
500 Special/Athletic	24.8	32.8	4.8	23.0
600 General/Campus	19.1	29.9	6.9	19.0
700 Support	22.7	25.8	3.6	23.4
000 Inactive	5.3	5.0	1.6	4.6
Subtotal:	**181.6**	**220.7**	**55.4**	**171.2**
800 Health Care	12.6	1.4	0.0	8.7
900 Residential	43.3	94.3	8.5	44.2
Mean NASF Per Student by Sector	**237.5**	**316.4**	**63.9**	**224.1**

The Facilities Management departments play an important supportive role in the attainment of the intended design objectives for the physical space. Facilities Management process has its roots in the custodial role of buildings, concerning the operational issues of maintenance, cleaning and tenant security (Best et al 2003). As buildings are becoming more complex and delivered at higher costs, the need to introduce tactical and strategic short term and long terms facility management functions is becoming more important. Along these functions, other support functions such as the management of human resources and information technology are also becoming important.

Facilities Management departments vary from one organization to another due the fact that they are developed to respond to the particular needs of their organizations. Barret and Baldry (2004), in their book proposed the following categories:

- Office Manager. In this model, FM is not usually a distinct function within the organization; instead it is undertaken by someone as a part of their general duties.
- Single Site. This model applies to organizations that are large enough to have a separate facilities management department and are located at just one site.
- Localized Site. Applicable to organizations that have buildings on more than one site, most often within the same metropolitan area.
- Multiple Sites. Applicable to large organizations that operates across widely separated geographic regions, probably nationwide.
- International. Applicable to large international organizations, that in addition to size, deals with international legislations, language, etc.

These categories are focused on the size and geographical distribution of the buildings, but there is also variation in the FM department organization depending of the type of facility: Health, Residential, Industrial, Education, etc.; or by the nature of the organization: Public Sector or Private Sector. The bottom line is that FM organizations varies from one facility to other, in the same way the kind of information the FM staff needs to do their job is also dependent to the type of facility. Regardless the different models of FM departments there are always three types of inputs for the facility managers to conduct their work and these are: the Organizational input, the Facilities Department input and the Facility -itself- input (Teicholz 2013a).

The functions of a Facilities Management staff are aligned to support and work together with the Human Resources Management and Information Technology Management. Facilities management plays a key role in the operation of an organization; they are in charge of maintain the physical environment for the organization to operate. The functions of the FM discipline can be grouped in two major categories, the first category relates to the functions of the business model, in which it provides the information needed to certify that the operation of the facility is in compliance with codes and regulations; also in this category are functions that provides the information needed from the facilities in relation with the business model and financial planning. The second group of functions is related to the buildings including new developments and; conditioning and maintenance of the actual ones. Both categories are strongly related (See Figure 1).

The Facility Management process covers a wide variety of tasks going beyond the performance of operation and maintenance of the buildings and grounds and keeping records and inventories of facilities and their maintenance schedules at operational level. It can be considered a total process that operates at three levels: strategic, where key planning decisions are made; tactical, where analysis and design processes take place; and operational, where implementation and day-to-day running of facilities processes are handled. A key element for the success of effectively managing the maintenance of the assets is to have continuous and reliable information about the asset inventory, condition and performance. This information is the most valuable asset for the decision makers. Quality information comes with a price, and few organizations can have the appropriate quality level of the information and a positive return of investment at the same time, in other words, obtaining a reliable and highly accurate information usually cost more than the possible benefit of having it. This is mainly for two reasons, the approach of acquiring the information or the sub-utilization of such information.

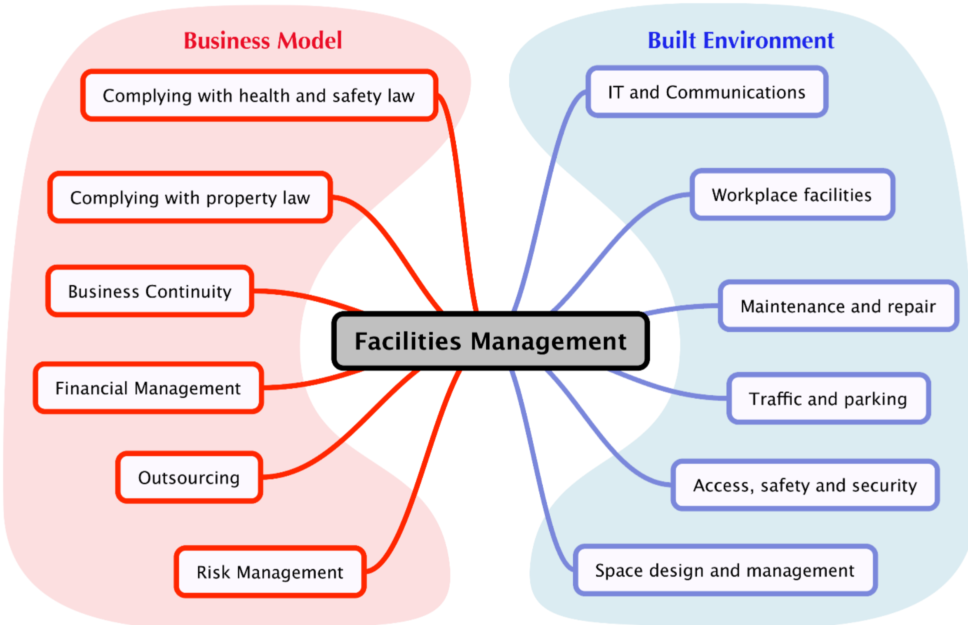

Figure 1 Facilities Management Functions

Operation and Maintenance of a facility takes place after the construction is finished. It is usually the longest phase in the lifecycle of a constructed facility and the one contributing the most to its lifecycle cost, up to three times the construction cost (Fuller 2010). The facilities management staff are the people in charge of the operation and maintenance of the facility and they deal on a daily basis with information regarding the built environment (facility input), such as technical description of materials, products, equipment and systems; warranties and guarantees; equipment operation, maintenance manuals, as-built drawings among other. This information is handed over to the owners after construction, usually in the form of electronic documentation in a CD media or, in the worst case, in a big box of printed papers (East 2007; Goedart & Meadati 2008).

Gathering and organizing this information on a typical building after occupancy can usually take up to six months or more and, according to the National Institute of Building Sciences (NIBS) can cost between $25,000 and $40,000 (Freeman 2009). A study made by the National Institute of Standards and Technology (NIST) to estimate the efficiency losses in the U.S. capital facilities industry, reported that the annual cost associated with inadequate interoperability among computer-aided design, engineering, and software systems was $15.8 billion (Gallaher et al 2004), two thirds of that cost are result of the ongoing facility operation and maintenance, see Figure 2 and Figure 3.

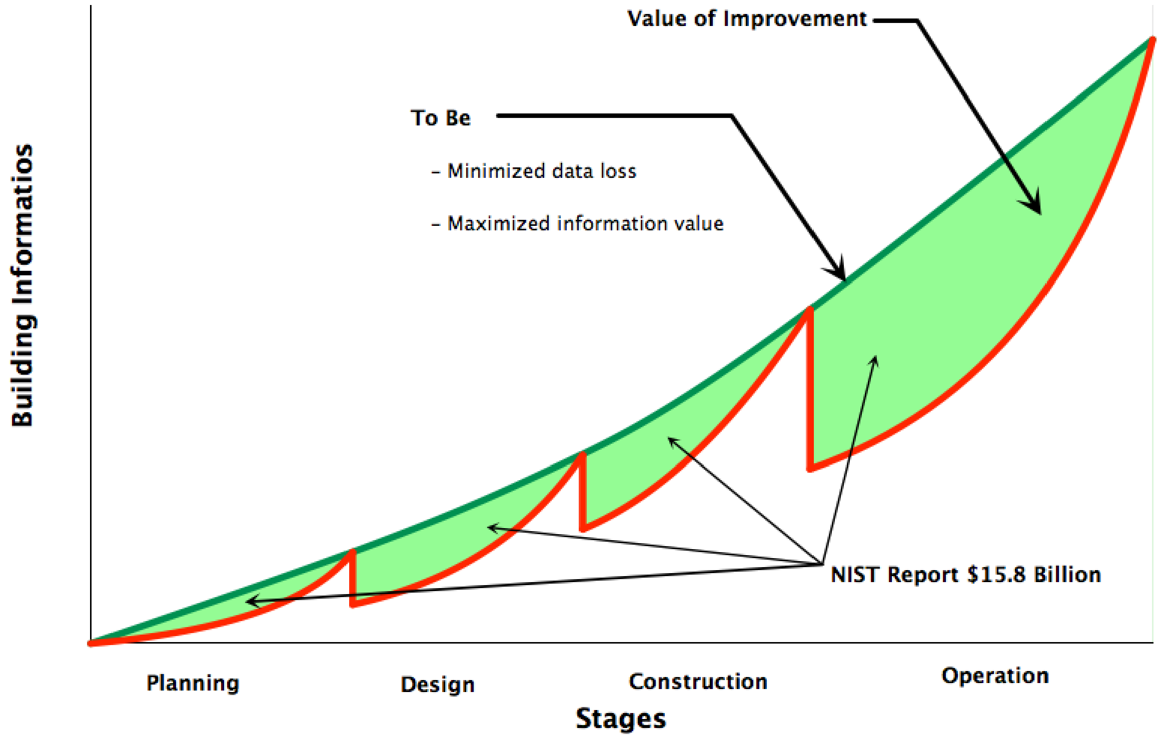

Figure 2 Data Losses in the Building Life Cycle. (Based on the graph of Smith & Tardif 2009)

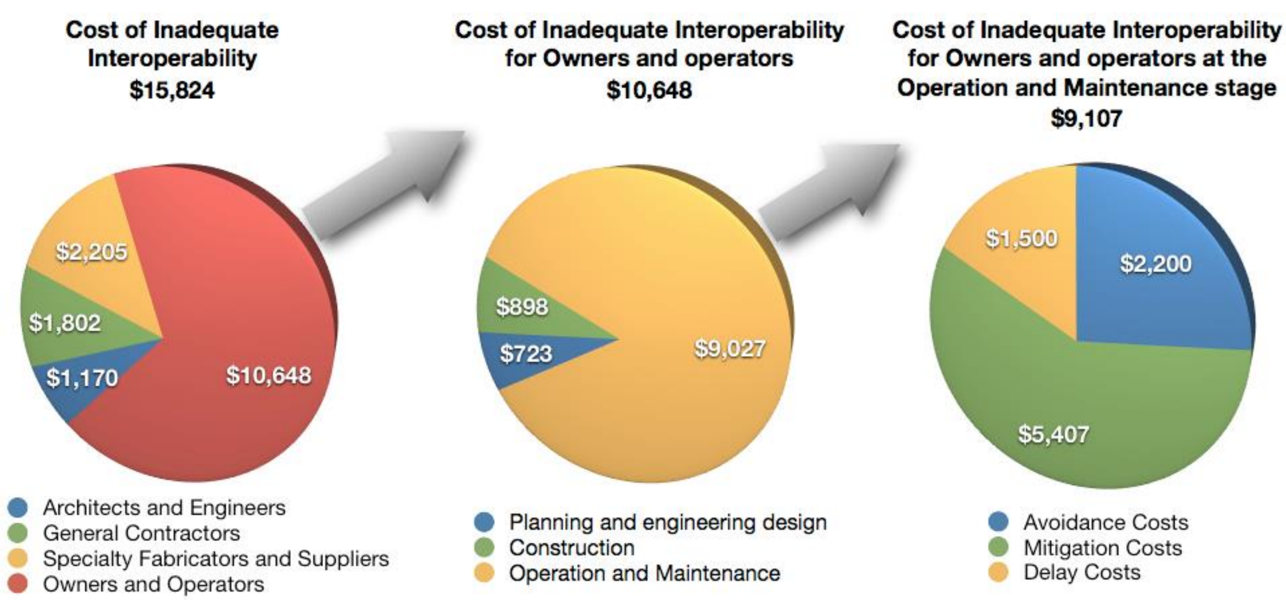

Figure 3 Costs (in millions of dollars) of inadequate interoperability. (Gallaher et al 2004)

Figure 3 shows the breakdown of the costs of inadequate interoperability focused on the owners: of the $15.8 billion total, $10.6 billion (67%) corresponds to cost for the owners and operators, then, from here $9 billion (85%) occurs at the Operations and Maintenance stage, these costs are distributed in three categories, 1) Mitigation Costs $5.4 billion (59%) those are costs incurred by organizations to resolve inadequate interoperability problems after they have occurred, such as manual reentry of information, verifying that users are proceeding with the correct files and rework due to proceeding with incorrect information obtained through inadequate information management exchange; 2) Avoidance Costs are $2.2 billion (24%), those are the costs and organization incurs to prevent the occurrence of interoperability problems, basically those are the cost associated to the use and maintenance of redundant information technology systems including: licensing, training, support by the IT staff, data translation, research and development, among the most important; and 3) Delay Costs, $1.5 billion (16%) cost mainly related to labor charges for idle employees.

Interoperability problems in the capital facilities industry stem from the highly fragmented nature of the industry, the industry's continued paper-based business practices, a lack of standardization, and inconsistent technology adoption among stakeholders (Gallaher et all 2004)

The University of Utah reported 22 electrical outages accounting for more than 300 hours without power for the year 2008; for 2009, 105 days were recorded with no heat or hot water for 65 buildings due to a line break, and in January 2010 the same issues were present in 44 additional buildings (Douglas 2012). For this particular case the Facilities Management staff pleaded for the necessary funds to sustain the old facilities in operation, but it was not clear if this what the real issue or if it's a matter of having the adequate information to prevent the failure or at least to act promptly and solve the problem quickly. Owners need to be certain on what is the root cause and the countermeasure to avoid that kind of scenarios.

For Maintenance & Operation to perform effectively a reliable listing of all assets and their conditions needs to be present. The project information delivery regarding what information needs to be delivered, who delivers the information, when is it going to be delivered, and how is it going to be delivered (format) of the asset, needs to be transparently transmitted to the FM staff; an audit in the project handover is fundamental to ensure the information is complete, consistent and with the appropriate format (Douglas 2012). This information is then managed by the FM staff that usually relies on the use of some computerized system to handle the great amounts of data.

During the process of operating and maintaining a facility, It is a common scenario that the existing facility management software is underutilized and poorly implemented (Lewis and Whittaker 2012), this is mainly because of two reasons: the enormous task of populating the system, and thereafter the permanent and continue maintenance and updating of the such information every time the facility suffers a renovation, a change of configuration, an equipment or system is replaced, a maintenance is done, and so on; the second one is the mismatch of the software purposes with the needs of the FM staff, resulting in multiple software packages for supporting the whole process or doing some manual information management because the lack of some specific functionality of the software, later such scenario derives in poor performance of the FM staff or higher operations costs, such as those showed in figure 3.

2.2 The handover process

The handover process consists in providing the owner with the information of the design and construction related to the facility, the owner through the facilities management staff uses this information to operate and maintain the facility in optimal conditions. The handover process delivers information that is generated during the different phases of the development of the physical facility. Therefore, is important to understand these phases and what information is gathered in each. The phases of the lifecycle of a physical facility are:

- Planning and programming
- Design
- Construction
- Close out and commissioning
- Operation and maintenance
- Disposal

In figure 2 four phases are show for the project life cycle, for the purposes of the genesis of the information close out and commissioning, that is usually part of the construction stage is presented as a separate phase, the same situation happens with the disposal which typically is considered as para of the operation and maintenance.

2.2.1 Phases of a facility and the information valuable for facility management

Planning and programming

This is initiated by the user of the facility, in this phase the information requirements came from the user needs and evaluation of the assessment of the condition, capacity, efficiency and operating cost of the existing facilities, to determine if a new facility or renovation of the existing is needed.

The requirements for the new facility are recorded in the architectural program. The program is a comprehensive report that includes the facility requirements, included in the report are primarily the spaces listings by function and size, information that will be useful for the FM staff for the entire life of the facility.

The programming is the transition between planning and the design.

Design

The design translates the program requirements into a comprehensive description of the facility in terms of geometry and functional and operational characteristics and presented in graphic and text form through drawings and specifications. This phase creates a large amount of information essential for the next phases of the project life cycle. This is a complex process in which many organizations and specialists are involved (architects, civil engineers, structural engineers, building and production systems engineers, interior designers, cost estimators, etc.), these individuals may be affiliated to one or many organizations.

At the end of the design phase all of the systems of the facility are defined, this is meaning the al the basic information for such systems is already defined, what is missing is the information that is defined when the installation and startup of those systems, which occurs in the construction and commissioning phases.

Construction

Construction transforms the design into a physical facility and makes it a reality. Building contractors use design information as an input for building the facility. New information is as fabricators, vendors and suppliers provide more detail for the systems of the facility, or changes to the original design scope take place adjusting layouts, and/or functional characteristics. All of the information that suffers modification or adjustments needs to be updated to reflect the actual realization of the original design and for the future use of the facility managers.

Construction is a process focusing on the physical execution of the project as well as the documentation of all the changes and adjustments made during the process. It involves many parties adds complexity to tracking and documenting such information. The efficiency and accuracy of the documentation of this information depends highly on the type of project delivery and on the reliability and practices of the parties, typically the general contractor or construction manager in responsible for this documentation. It will help him to negotiate changes in the price but also will help to update the information of the design.

This changes documentation will allow the main contractor to create the as-built documents, which is a common requirement to be included in the handover.

Close out and commissioning

This is the final stage that serves as a transition between completion of construction and initialization of operation. This is also the last opportunity to gather information from the design and construction teams. Commissioning is the systematic process of ensuring and documenting that all systems and assemblies perform according to specification and end user requirements, as well as the owner's operational needs.

In this phase the construction work is approved by the local authorities and accepted by the owner, and all the necessary information to operate and maintain the facility is turned over.

In this phase the building and production systems are started up, occupancy certificate is issued, operation and maintenance training is conducted, record plans (as-built) are submitted, operation and maintenance manual are submitted, as-built schedule is generated and final inspection is performed, among other processes.

This information is handed over to the owner by the construction team.

Operation and Maintenance

The operation and maintenance phase is the longest and contributes the largest part to the lifecycle cost of the facility, because the life of a facility can be extended over decades or centuries. Therefore, this is the phase that benefits the most from the information that was handed over to the owner organization by the design and construction contracted professionals.

Typically FM departments and organizations utilize a Computerized Maintenance Management System (CMMS) and/or a Enterprise Asset Management System (EAMS) system to store and manage information related to the operation and maintenance of their facilities. Populating the systems with information handed over by the contractors after construction is completed is a major task that may take up to six months to be completed at a level that allows proper operation.

In the long life of a facility, renovations may take place at different stages and for different purposes. When this is the case, old and updated information of the facility becomes extremely valuable for the planning design and construction. As the renovation process takes place newly generated information needs to be documented and become part of the existing FM information systems.

Disposal

Disposal of the facility implies demolition or transfer of the asset. For both cases information is needed to proceed, in the case of demolition information requirements include the types and quantities of material to be removed, salvage values of equipment, and structural information to define the demolition strategy. If the facility is to be sold, information of the current condition of the facility, remaining life of building systems and land value are required.

2.2.2 Delivering the information at the end of construction

The handover process and the information that is required is well described in the document from FIATECH, "Capital Facilities Information: Handover Guide" (Fallon and Palmer 2006) this section discusses its main content.

The handover process consists of the following stages:

- Facility life cycle information strategy
- Handover requirements
- Project information handover plan
- Implementation

Facility life cycle information strategy

In establishing a facility life cycle information strategy, the organization examines the business regulations, decisions and processes that require facility information and defines the precise information required by each (known as an "information package"). It prioritizes information packages based on the business value; if a certain information package is used in much business process, it increases its value. Another way to find value on the information is looking at processes that are inefficient or costly due the lack of information.

The facility lifecycle strategy must include in most cases:

- Management policy statement
- Conformance of the information handover with the organization policies.
- Identification of mayor information packages to:
    - Establish priorities
    - Identify for whom and when in the facility life cycle is this information created
    - Identify for whom or for what process and when in the facility life cycle is this information created
- Assigning responsibilities for:

- Establishing appropriate contractual and procurement terms.
- Ensuring security policies of the information
- Coordinating the handover delivery process
- Establishing the system infrastructure for receiving the information handover
- Assuring the information quality of the handover
- Maintaining and managing the information handover through time

Handover requirements

The way in which the information is used determines its properties and appropriate form and format.

The information packages have three major properties:

- Status

  For each information package, it will be necessary to identify which status is needed. The status of the information changes though the facility life cycle, normally under configuration control, for example "issued for review", "issued for construction" or “as-built".

- Type

  There are two types of information packages, Static and Dynamic, Static is the information that is never updated, such as certificates or inspection reports. Dynamic is the information that needs to be updated, and also for this kind of information the need for past revision or the revision history discarded should be determined.

- Retention

  If some information is not available the organization suffers the consequences. The severity of the consequences determines the importance of the information. When there are no consequences, maybe this is a signal that this information shouldn't be included in the handover. Special care should be taken when deciding that some information should not be included in the handover because in some cases regulatory requirements may demand keeping this information, even when is not of use for the operation of the facility.

The minimum set of categories can be the following:

- Essential

  Information required for the operation of the facility. Without this information, an unacceptable risk would be created with regard to reliable operations and safety. This information must be retained for the full life cycle of the facility.

- Legally Mandatory

  Data that is not expected to be referenced on a regular basis in the operations phase however, there is a legal or contractual obligation to archive the information for a specific retention period. The retention period must be explicitly defined.

- Phase Specific

  Data developed in one facility life cycle phase that are deemed useful for a subsequent phase but not for long-term operations. The use phase must be specified.

- Transitory:

  Data that is not required to be referenced in any of the subsequent life cycle stages.

Information Forms and Formats

Traditionally, the handover is a paper-based operation, or a combination of paper printed documents along with digital (raster image) versions of printed documents. However this has proved particularly unsuitable for the use, management and maintenance of such information, because the only way to do it is manually, and considering the amount of information to be handled, makes this task not feasible.

Nevertheless, the facility information is, now more than ever, produced and handled electronically. However, much of the information does not have a formal structure; therefore, the only way to understand or check the quality is actually by reading the document, slowing the process of transferring this information to the computerized systems for managing the information and making it prone to error or omission through the transcription process

Some new approaches can provide facilities information in a structured form that is immediately machine-interpretable, increasing productivity and reducing errors. Even graphics and drawings can be managed in a structured form.

There are four major categories of information, structured and unstructured and both can be proprietary or standard. Structured information promotes reusability of the information, while standard information promotes longevity of the information (see figure 4)

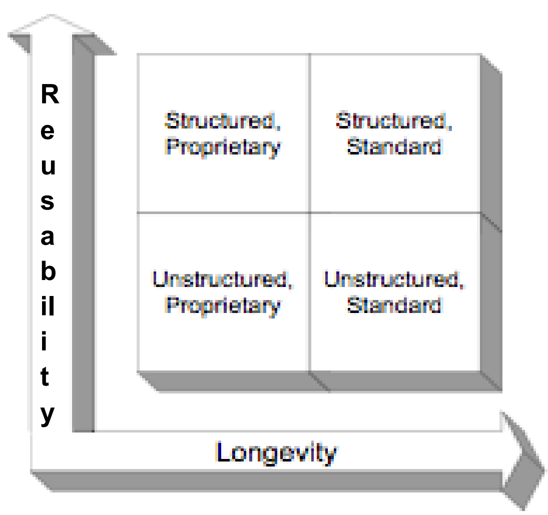

Figure 4 Information format (Fallon and Palmer 2006)

- Proprietary format

  Also referred as “native” is the information produced by specific software, and at any time the software vendor can modify the format, this in detriment of the interoperability as the receptor software should update its data importing procedure. Even worse, the format can be discontinued.

- Standard format

  There are two types of standard formats:

  “Ad hoc” standards which may have originated with a single software vendor, but have been made publicly available and are supported by multiple vendors, as for example the Portable Document Format or PDF from Adobe® and; “Formal Standards” which are those maintained by an official standards organization, typically developed through a consensus process that consider information requirement from multiple organizations, such as the Industry Foundation Classes or IFC maintained by the Building Smart Alliance.

- Structured data

  The structured data can be accessed and manipulated directly by computer applications, without human intervention, and it is adhered to well-defined model. Structured data can be quantitative, descriptive or graphical. This kind of information allows automated search, retrieval and update, therefore is cost effective.

  Proprietary software commonly uses structured data, and proves it benefit during the limited time the software is used, unfortunately no software covers all of the phases or specialties involved in a facility, therefore the software must be capable to export its information in a structured and standard format in order to provide interoperability, as is the case of the IFC.

- Unstructured data

  Any data that cannot be machine-interpreted are unstructured data. Not all of the software uses structured data, digital images for example is unstructured data.

  Documents containing information with unstructured data can be easily filed, retrieved, tracked and monitored with the support of metadata; however, machine interpretation is really difficult and requires more manually-intensive processes.

- Metadata

  Metadata is defined as data about the data and is used to organize the information system and search for particular items.

  As information is organized and classified during the different phases of the life cycle of a facility by the different participants, a comprehensive metadata approach is necessary, particularly for the long-term data access and preservation through all the facility life cycle phases.

There are three types of basic metadata:

- Descriptive metadata identify and describe the general information of the document, such as title, creator, subject, etc.
- Administrative metadata are used to manage the information such as file size, file format, creating system, archiving date, etc.
- Structural metadata describe the internal structure of the information and relationship between its components, for example the set to which a single drawing belongs, the multiple revisions of a document or the link of the document to another documents.

Project information handover plan

The facility life cycle information strategy and the handover requirements are generalized for any facility type, the challenge of the project information handover plan is to apply these general requirements to the specific project so that high-priority, correct and properly formatted information packages are dependably, timely and cost effectively handed over by the originating members of the project team.

The project information handover plan should make clear:

- Who will produce each required information package?
- How will they deliver the information package?
- Who will receive the information handover?
- Where will the handover information be stored?
- Who will be responsible for its management and integrity?

The key point that all project participants must understand is that information should be managed for the whole life of the facility and not just for its immediate use. Therefore, the information must be created and managed not only to meet the immediate procurement need, but also for its reuse throughout the lifetime of that item of equipment.

The handover plan contents:

- Information packages
- Project-specific information package sources and phase when produced
- All uses of priority information packages generated during the project in subsequent life cycle phases.
- Format for each information package.
- Required metadata.
- Clear assignment of responsibility for all information creation and handover activities.

The handover method will depend on the format of the information, organizations have to continue with the use of printed document by law requirements, but technology is facilitating the delivery of electronic information. For this, the options for handing over information goes from the simplest method that is an organized set of Portable Document Format or PDF files with the information, to the most advanced option that is the owner provides controlled access to the members of the project for uploading deliverables or populating the system.

The electronic method depends on the information format and the information management system the organization is using.

2.3 Building Information Modeling

Building Information Modeling (BIM) is one of the most promising technologies for the Architecture, Engineering, Construction and Facilities Management (AEC/FM) industries. Building information models encapsulate and represent the three-dimensional geometry of building objects and the corresponding attributes of a physical facility. By its very nature, it promotes collaboration from design and construction participants around the digital model of a facility. The core of BIM is the building geometry, but also is a structured information base of non-graphical data that provides detailed information about the identity of building components and their properties, for example: a wall element in a model exists as a wall and is no longer represented by a set of drawn lines.

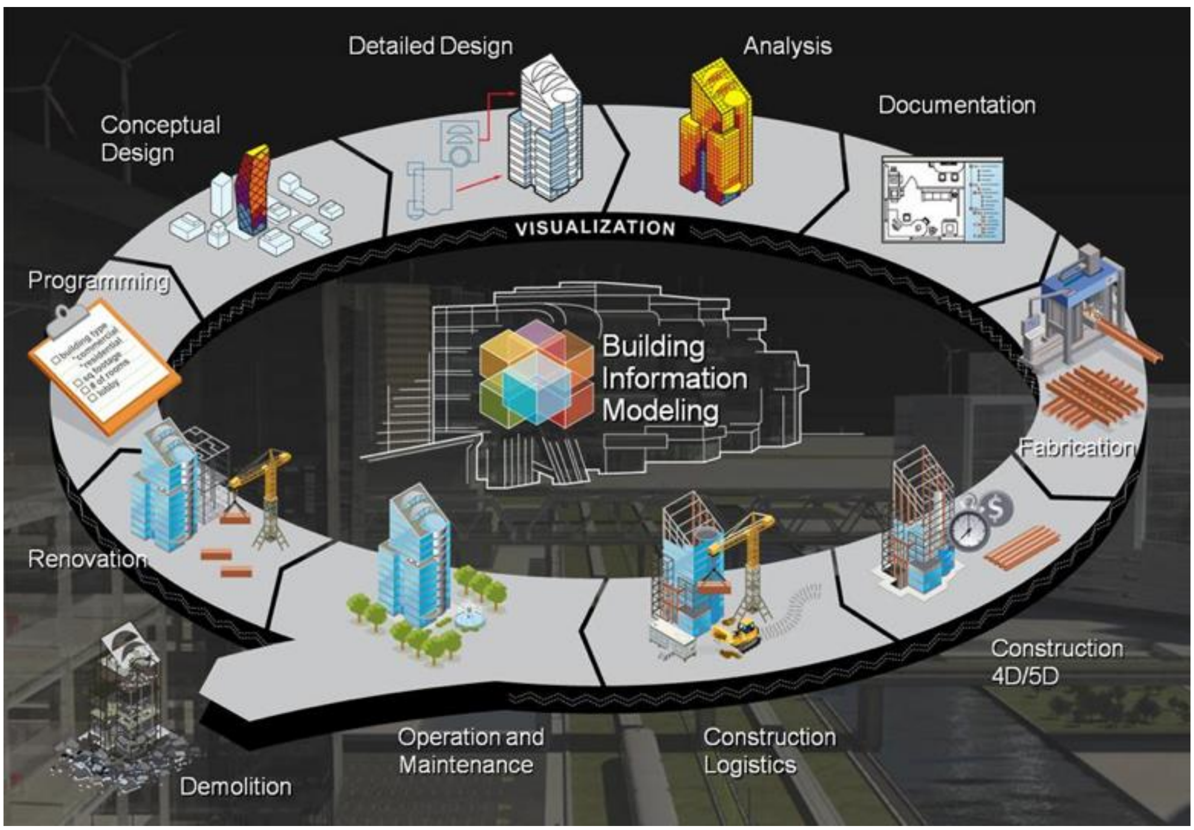

Figure 5 Collaborative and Integrated view of BIM through the project lifecycle, Image courtesy of Autodesk®

The National Building Information Model Standards (NBIMS) vision for BIM is: “an improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle” (NIBS 2008). This definition implies a collaborative and integrated approach (see Figure 5)

The adoption of BIM has grown from 28% to 71% in the construction industry between 2008 and 2013. In the first and second BIM SmartMarket Report research studies, published by McGraw-Hill Construction in 2006 and 2009 (McGraw-Hill Construction 2012), architects led the industry in BIM use by a substantial margin. In the most recent study conducted last fall, contractors are now the leading users of BIM, between 2009 and 2012 the percentage of contractors using BIM increased from 50% to 74%, while the architects remains in the 70% of whom now reports using BIM. (Bernstein & Jones 2012). In this way, BIM is beginning to take the place of conventional 2D drawings and printed documentation in the generation of design documentation for a building. BIM has proved its value in so many discussions about the Return of Investment (Giel & Issa, 2011), and maybe now is the time to ask this questioning from a reverse angle, that is, in determining if the value of BIM is better assessed by the cost of not doing BIM (LeFevre, 2011).

BIM is mainly used during design and construction phases; however, its adoption for the FM process is a more complex issue and less straightforward when compared with its use in design and construction. BIM offers valuable information that is generated and gathered as the model is created and used for several purposes during the planning, design and construction stages of the building. Extending its use for supporting the FM process has the potential to reduce and simplify the collection of information needed by facilities management staff since a significant part of it has already been gathered and stored in the model (Nawari, 2012).

When BIM has been used for the design and construction of a facility a non-value-added effort occurs every time that a non-integrated phase of the project takes place; designers, contractors or commissioning agents typically generate and collect a minimum of two times this information without necessarily sharing with the facilities management staff (East, 2007) therefore an effort is needed to enter again the information that is not shared by the previous phases. BIM could enhance the efficiency of transferring information during the handover process to facilitate day-to-day operations of the facilities management staff.

The use of BIM does not intend to replace the current set of information technologies that are commonly used by FM staff, but can support, leverage and enhance them. BIM can potentially offer important advantages for the FM in the following ways:

- Standardizing project information delivery.
- Offering a unified information base.
- Providing effective support for analyses.
- Enabling location-aware model of equipment, fixtures, and furnishings, with the associated data.
- Supporting for emergency and security management and scenario planning.
- Providing the power of visualization to data.

However special care needs to be taken to avoid that BIM becomes one more software packages to maintain. It rather should integrate to the current software packages to facilitate and optimize the use and maintenance of them.

2.4 BIM and FM

Facility managers are continually faced with the challenge of improving and standardizing the quality of the information they have at their disposal in order to meet the day-to-day operational needs, as well as to provide reliable data to building owners for life-cycle management (Teicholz 2013). BIM is positioned to offer a new level of functionality for managing buildings and its related physical assets, this is motivating organizations to begin adopting BIM for FM

BIM is beginning to being implemented for facilities management, for example, the U.S. General Services Administration (GSA) is requiring delivery of spatial program information from building models for major projects; the U.S. Presidential Executive Order 13327, promotes the creation of a common infrastructure to facilitate effective information sharing/reuse. Under this and other premises, the GSA, one of the largest building owners of the US, is defining and testing its roadmap for the BIM during the FM (Foster 2011). GSA is currently manually populating their Computerized Maintenance and Management Systems (CMMS) after the handover process happened. GSA expects to automatize the data entry of the CMMS through the use of BIM.

GSA is facing in every hand over process with an overwhelming amount of information, they are dealing with the “tsunami” of information (see figure 6) that Birgitta Foster conceptualized and presented during the 2012 conference of the BIMForum in Tacoma, WA. This “tsunami” of data is originated at the early stages of the project, during the planning, then through construction and commissioning it is transformed into a “monster wave”. The analogy of the “tsunami” continues as it discharges an overabundance of data into the FM department where the staff needs to filter-out all of the information not useful for them, and maintain only the one they need, then this information needs to be organized and filed for later use. This non-value-added process may take up to up to six months after the project turnover (Gallaher et al 2004).

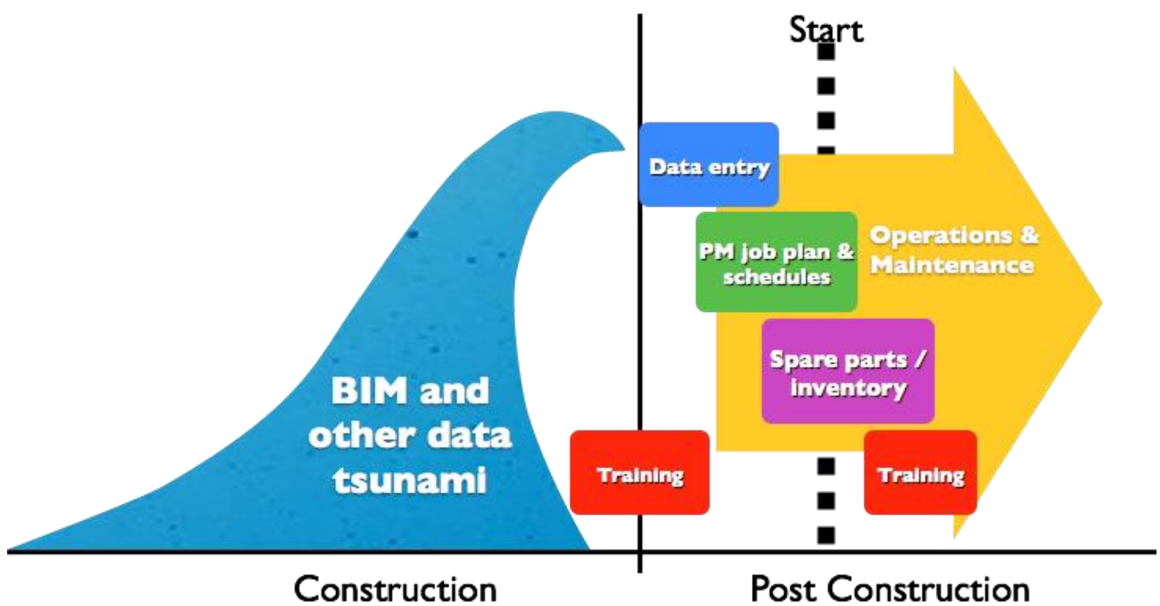

Figure 6 Data tsunami vision. (Foster 2012), adapted by Alvarez

GSA has initiated several pilot projects to investigate the implementation of BIM for FM (Yee et al, 2012), the lessons learned up to now are: early involvement of the facility manager is key to understanding the priority of data to be modeled; a BIM execution plan to help define the responsible party or parties entering data and how it will be used; mock-ups of the user interface helped FM staff to understand how they could benefit from data.

GSA is strongly relying in the Construction Operations Building information Exchange (COBIE) specification to implement this process. The COBIE project initiated in 2005 by The Facility Maintenance and Operations Committee of the National Institute of Building Sciences, the pilot standard was released in June 2007. In December 2011, it was approved by the NIBS as part of its National Building Information Model Standard (NBIMS-US) standard. Today COBIE can be created and exchanged by the use of some commercial software systems; also, it can be created and exchanged using simple spreadsheets. The COBIE approach consists of entering the data as it is created during design, construction, and commissioning. COBie is further discussed in section 2.5

One of the main limitations of COBIE is the lack of support to this specification by software vendors, therefore, the adoption of the specification is very slow. In 2009 the State of Wisconsin started requiring the use of BIM on all projects totaling more than $5 million and new construction projects of more than $2.5 million (Beck 2012), later the state conducted a series of pilot projects to verify the data exchange methods between architects and engineers, contractor’s BIM models and the FM applications. The research found that very few contractors understood what they were asking for when inquiring about COBie exports from the models, the only format that was easily obtainable was the raw Industry Foundation Classes or IFC (see section 2.5 for IFC discussion), for that reason the state decided to adopt IFC as the base format for updating its AE BIM Guidelines.

COBie eventually will be able to provide the structure to seamlessly transfer the data from BIM applications to FM systems, however, today practice COBie relies on the organization of data in a series of structured and related spreadsheets and only some of the data deliverable by the COBie approach, can be developed within the BIM authoring application (Teicholtz 2013).

The IFC specification (Building Smart International, 2013) was originally developed in 1996 by the International Alliance for Interoperability (IAI). It is currently developed and maintained by the Building Smart Alliance as its "Data standard". The current version of the IFC is the IFC4 (Building Smart International, 2013) which was released on March 2013 (see section 2.5 for further discussion on IFC). The IFC is becoming the more widely supported standard by BIM software vendors However, because of all of the enhancement that proprietary systems add to the model entities in comparison with the ones included in the open standards entities open standards will never be able to exchange all the data that two software could exchange (Moor 2011), . This fact does not invalidate the need for open interoperability standards.

As well as with the open standards, successful approaches have been made using proprietary standards, such as in the case of the University of Massachusetts Medical School, where recently they finished the Albert Sherman Center, a 515,000 SF, 11 stories high, 9 occupied stories topped by two-story mechanical systems penthouse (Baker et al, 2013). This project was developed with the vision of using BIM beyond design and construction and incorporating it for facility planning, operations and maintenance. In this case a model is integrated into the current facilities building management system, the model is a full spatial as-built; includes the design and actual capacity of the building systems; contains assets tagging; has the ability to isolate a system and; has a database for the non-graphical documentation linked to the model. Through the use of Autodesk Navisworks® it integrates 11 different but coordinated model files into one single viewable model file. This software is also used as the interface to query the building model for retrieval information associated to the building components. The approach uses Microsoft Share-point as the container of non-graphical information (warranties, specifications, O&M manuals) that is linked to the model objects, and therefore the retrieval of this non-graphical information is also made through the viewing model. The Navisworks® interface also allows the FM staff to create and manage work orders for maintenance. In this case no open standard were used to deliver the handover building information, instead they used the native formats of Microsoft and Autodesk for this purpose. Two major characteristics of this project are: the deliverable is not a set of files to populate the current building management system, but a ready-to-use BIM-based building managing system integrated to their current building information system; the second is that it uses the BIM model to query and manage some of the FM tasks.

Universities are making great advances on implementing BIM for the operation and maintenance stage (see Figure 7), The University of Southern California (USC) is successfully linking real time sensors placed on building systems to the BIM, focusing on the Mechanical Electrical and Plumbing (MEP) systems for real time monitoring and for the system alert in real time in case of the occurrence of emerging problems. To obtain the models, USC is requiring in its BIM guidelines the use of BIM authoring software such as Autodesk Revit® and Civil 3D®, and Tekla® for their new projects, They have adopted COBIE format to populate their FM information systems, for that reason, they are also requiring the use of Ecodomus®, for the creation of the COBIE files. Many other universities in the US such as Indiana University, Massachusetts Institute of Technology, Xavier University, Pennsylvania State University among others, are developing their guidelines for the use of BIM, and some of them are requiring BIM for their new projects. COBIE is presented as the standard of choice in many of this guidelines.

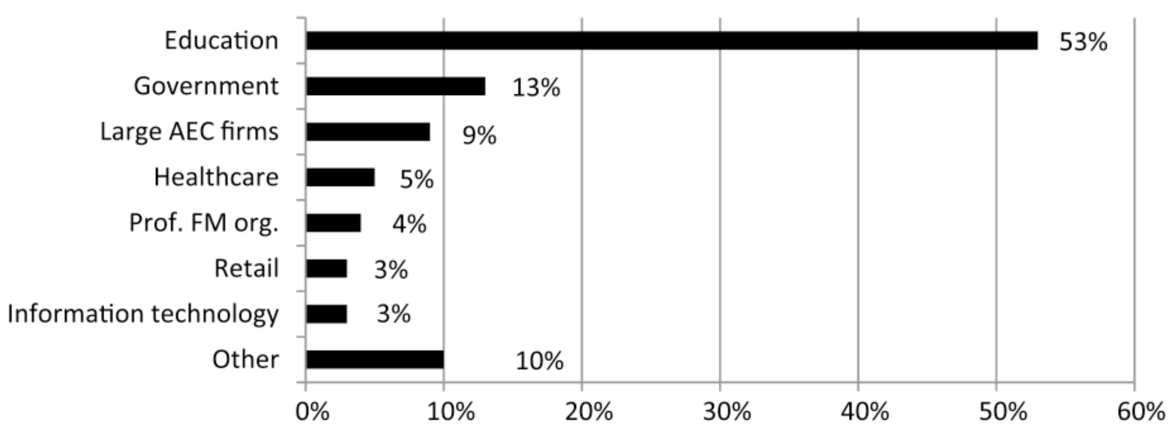

Figure 7 Status of BIM Implementation in Facilities Management Practices (Brecerik et al 2012)

It is perceived that BIM for the FM is currently gaining momentum, just recently the BIMForum conference held in Tacoma, WA on October 2012 were entirely dedicated to the use of BIM for FM. It is also clear that the use of BIM to include the operations and maintenance stage has begun, BIM seems to be the missing link for an efficient integration between the design, construction and the facilities management. However, the use of BIM to enhance the FM process carries its own challenges. One of these is that is common to the emerging BIM-FM integration approaches is its cost of implementation and its corresponding Return of Investment (ROI), Even though there are numerous case studies and discussions about the ROI derived from the use of BIM, those are somehow diverse and mainly determined for the design and construction stages and not for FM. In addition, the use of BIM by itself do not solve the issue of handing over the information that is needed by the FM staff. Finally, the way in which BIM could be used for the FM staff needs to be completely defined thus implying that a deeper understanding of the FM process is still needed.

There is not yet a “best practice” identified for using the BIM in the FM process, although facilities professionals are developing and instituting BIM guidelines and standards for their organizations. However, the use of BIM within FM varies depending on the organization needs and priorities (Teicholtz 2013), standardization is needed in order make the most of the momentum in the use of BIM which is present in the universities and colleges.

BIM authoring tools do not natively support FM functional requirements; however, BIM can potentially leverage informational needs for many of the buildings lifecycle management functions such as:

- Regularized project delivery

  Definition of the project BIM requirements to incorporate information needed specifically support the facility management after the handover.

- Space management

  BIM intrinsically incorporates3D spaces with data attributes appropriate for space management. With BIM it is possible to accommodate custom space management requirements and space measurement rules and its automated checking. BIM 3D visualization capabilities offers a better and more intuitive space layouts than a typical tabular data, for a better communication of space management and space assignment scenarios.

- Emergency management and security

  BIM provides an accurate three-dimensional representation of a building and its surroundings that as well as the corresponding attribute information can be used for analyzing and planning emergency response requirements and security measures.

- Display of real time data

  Some of the new technologies developed for BIM includes the capability to incorporate real-time data to the geometry of the building included in the model. This stands BIM as a 3D visual portal capable to access both, static and dynamic data on building components.

BIM applications need become more versatile for FM use in such a way to incorporate different functionality and more data centric approaches than the mere use for the design and construction stages.

There is also a critical need for a methodology and BIM definition that supports the rapid creation of BIM for the existing buildings. These are no models for design or construction, but 3d visual data models to support the workflow of the FM (Teicholtz 2013).

2.5 Industry Foundation Classes

One key issue for information exchange is to enable the interoperability between the different software tools used among the different project members during the whole life cycle. BIM authoring tools are diverse and every software vendor has its own proprietary format. Even between different software tools from the same vendor it is common to find interoperability issues. To mitigate the negative impact of having diverse proprietary formats, open standards are created that not only benefit users but also benefit software vendors. In BIM the most successful and adopted standard for interoperability is the Industry Foundation Classes (IFC).

The Industry Foundation Classes (IFC) is an open specification to facilitate the electronic information exchange of BIM object data. The use of IFC shows a great potential to facilitate the transfer of project object data from design and construction information to the FM in the case of the handover process.

The IFC protocol specification include terms, concepts and data specification item that originate from the use within disciplines, trades, and professionals of the construction and facility management. The Terms and Concepts uses plain English words, the data Items follows the IFC naming convention.

The data transferred through IFC is organized in four conceptual layers. Each individual schema is assigned to exactly one conceptual layer (See Figure 8). An IFC schema is a structural definition of the organization of a sub-set of IFC components, for one specific purpose.

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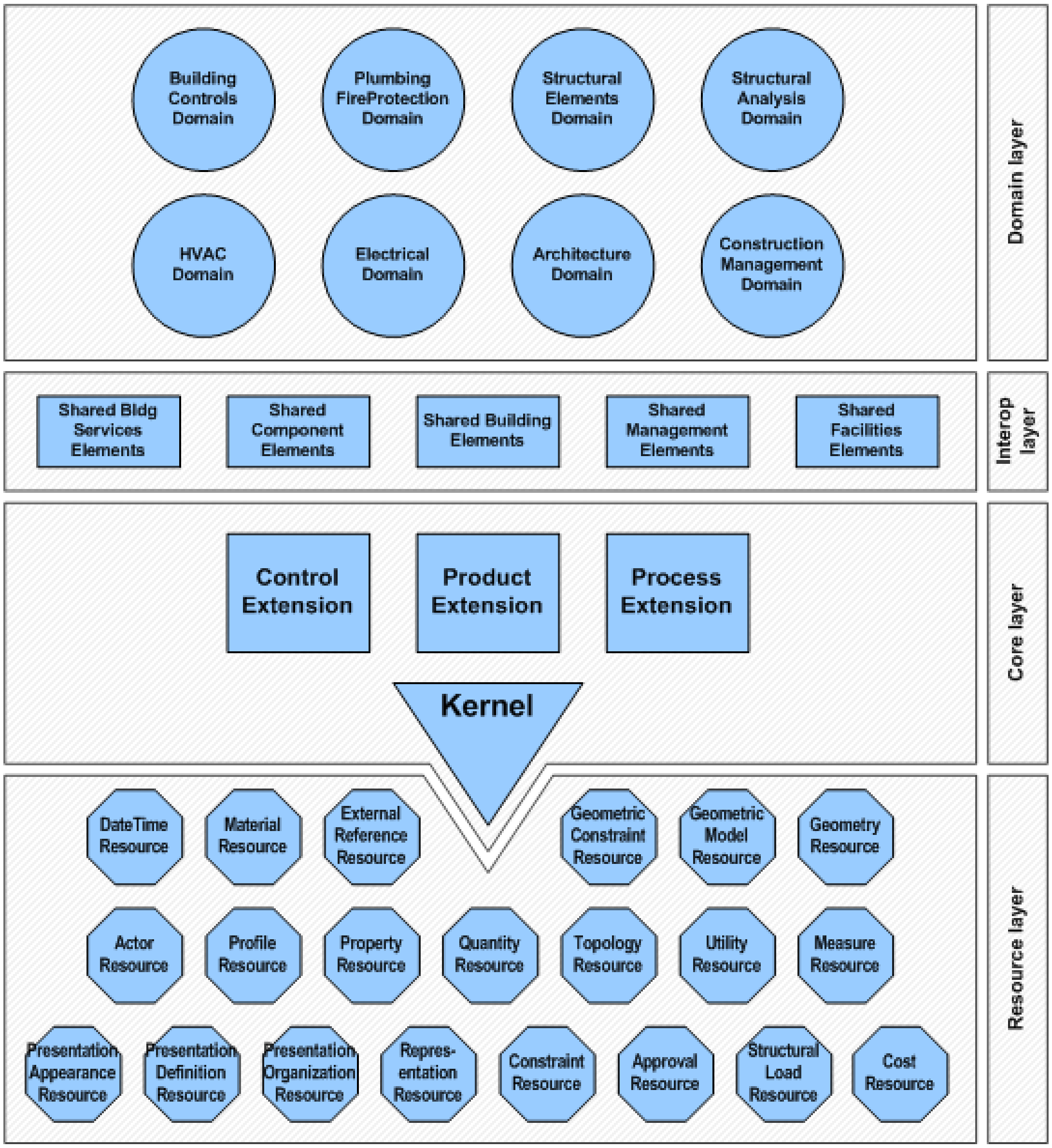

Figure 8 Data schema for IFC (Building Smart Alliance, 2013)

The specification includes information exchange requirement regarding:

- The life cycle of buildings:
    - Demonstration of need
    - Conception of the need
    - Outlined feasibility
    - Substantive feasibility study and outlined financial authority
    - Outlined conceptual design
    - Full conceptual design
    - Coordinated design
    - Procurement and full financial authority

    - Production information
    - Construction
    - Operation and maintenance
- The various disciplines:
    - Architecture
    - Building service
    - Structural engineering
    - Procurement
    - Construction planning
    - Facility management
    - Project management
    - Client requirement management
    - Building authority for permits and approval
- Other:
    - Project structure
    - Physical components
    - Spatial components
    - Analysis items
    - Processes
    - Resources
    - Controls
    - Actors
    - Context definition

The IFC4 specification was released, on March 21, 2013. It is the last update on IFCs and offers new capabilities that makes this release a powerful option when proprietary file exchange is not possible. Among the main new features of IFC4 are:

- Enhanced capabilities in its main architectural, building service and structural elements, with new geometric, parametric and other features.
- Enabled new BIM workflows, such as for the 4D and 5D models.
- Full integration with the new Model View Definition for the Extended Markup Language (mvdXML) technology and allows easy definition of data validation services, for IFC4 submissions.
- Enhanced geometry resource, adding support for non-uniform rational b-spline representation (NURBS)

The improvements in this version of the IFC overcome some of the limitations found in previous version that discouraged the BIM users to use this format for information exchange.

Using open formats as the IFC for the handover of information to the owner for operation and maintenance of the facility enables the owner to use low cost or free applications for viewing, manipulating and querying the model such as Autodesk DesignReview®, Autodesk Freedom®, Autodesk 360®, Tekla BIMsight®, Solibri Model Viewer® among others. The IFC allows the inclusion of the information that will be used by the FM staff. In addition, IFC can be prepared to comply with COBie definition for direct population of the CMMS, if the ROI justifies its implementation and the CMMS is COBie compatible.

2.6 Construction Operations Building Information Exchange (COBie)

The COBie approach was developed as an organizational solution to address the lack of standardization and organization of the several documents that are handed over to the owner at the end of the construction stage. The COBie approach is to enter the data in an pre-specified format as it is created during design, construction, and commissioning (Figure 9)

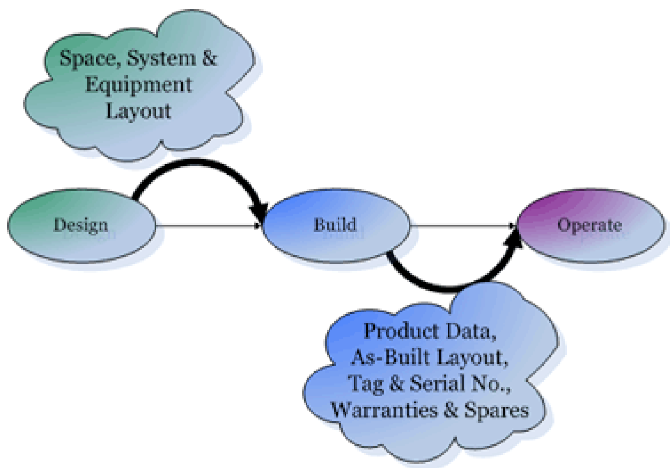

Figure 9 COBIE Process Overview (East 2007)

The COBie project was developed by the U.S. Army Engineer Research Development Center, in collaboration with the National Aeronautics and Space Administration (NASA), the National Institute of Standards and Technology (NIST) and other important organizations (East 2007).

The conceptual schema of COBie can be observed on the Figure 10, in it identifies two mayor stages of the project life cycle with different colors

The blue zone of the schema corresponds to the Design stage, which includes the planning and programing. COBie considers that in the early stage of the design the vertical and horizontal spaces are defined, as well as the different types of systems needed to fulfil the owner's requirements. This information can be captured by the COBie that organizes it in a structure with four levels: 1) Facility, 2) Floor, 3) Space and 4) Zones, the structure is not hierarchical, as the spaces can be organized by floor and also by zone.

The design concludes with the construction documents stage, which is also considered in the blue zone. In this stage all the materials, products, and equipment are specified. With COBIe this information is captured as components at the space level. The components are categorized by type and organized into systems.

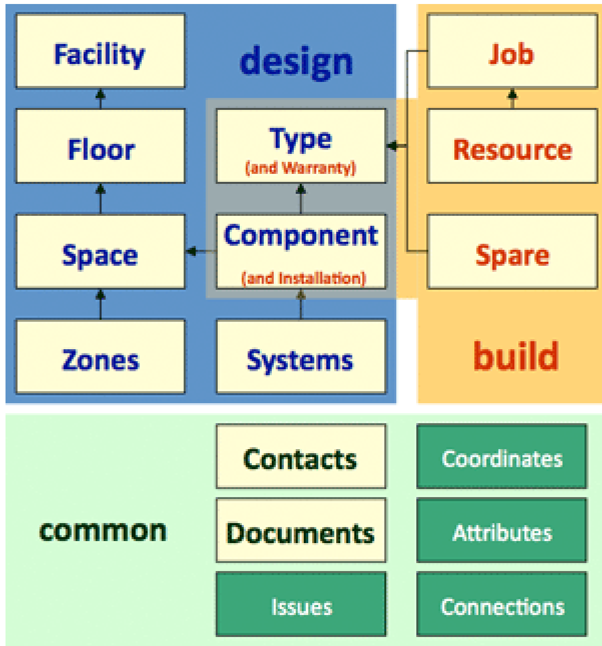

Figure 10 COBie Conceptual Schema (East 2014)

At the construction stage, colored in orange in Figure 10 above, the contractor provides submittals for the designer specified required documents. COBie allows electronic copies of acknowledged or approved submittals to be directly linked to specific types of materials, products, equipment, and systems. When the components are installed the last of their related pieces of information are added to the COBie; brand, model, serial number, and warranty information are defined and this information is added to the components already existing in the COBie model.

At the startup of the systems that occurs during the commissioning stage, the systems are tested and turned on permanently. At this point, several documents are produced describing these events, including instructions, test, certifications, and more details on warranty. The final stage of commissioning include the development of preventive maintenance plans for the long term operation of the facility. These include preventive maintenance schedules, shut-down and start-up procedures, emergency plans; this information is integrated into COBie as Job data (the process itself), resources (tools, materials needed in the process), and spare parts data.

In the COBie schema there is a green zone that contains information of common use for all of the stages of the project, such as contacts, documents (for attachment), issues, coordinates, attributes and connections.

COBie is a subset of the IFC definition, and it can be produced from an IFC model that contains the information needed to create the COBie model, alternatively the COBie model can be populated by manual methods using the spreadsheet representation of the model.

The OpenBIM network in the UK, did a project to validate and check the suitability of an IFC file for the generation of a COBie file and its use in real business (Malleson et al 2012). The results published in the IFC/COBie report finds that there is an overwhelming technical challenge for populating the attribute table, because of the lack of definition in the level of detail the information on the table should have. BIM object library authors and software vendors need to support the COBie file generation as a standard export routine, as this still does not happen the matching between the level of detail of the BIM and the COBie requirement is not clearly defined. As a consequence there is a considerable risk of missing data or to generate COBie files with a large number of rows of unworkable data. Therefore, the COBie export process is considerably a labor intensive one. The attribute naming system proposed by COBie sometimes is composed by information that is best suitable to have it stored in a separated field. The OpenBIM Network report also states that during the process of validating COBie the workgroup found few guidance on where the information to populate COBie should come from. It was not clear whether the information should come from the IFC file or directly entered manually. If the information should come from the IFC then issues regarding the support given by software vendors to their products and the known issues each software has on the geometry of the model when exporting from some BIM authoring tools, should be first solved. In the other hand if it should populated manually, the use of Microsoft Excel is fine for reporting but not good for authoring, is error prone and time consuming.

The OpenBIM network workgroup also found that the lack of robustness in the IFC export process with the BIM authoring software makes the manual checking necessary thus reducing the reliability of the automated process. The implementation of IFC for the generation of COBie implementation can be better supported directly by software vendors.

One of the main concerns of the work group is that COBie involves a great effort to produce, it carries some plausible benefits, such as to have the building data organized, however there is still not enough evidence that the demand COBie will be sufficiently used in the future in the operation and maintenance of facilities to justify the efforts to automate the IFC generation of COBie.

2.7 Conclusions

The handover process currently includes a substantial amount of manual work in identifying, sorting and organizing the building's information delivered at the end of construction. This effort was valuated in 15.8 billion, and caused primarily by interoperability-related issues among the different stages of a facility lifecycle.

BIM is emerging as a technology that has the potential to enhance and make this process more efficient. BIM is being strongly accepted by the construction industry and, many cases, it is being used at early stages of the project lifecycle. However, the Architectural / Engineering/ Construction / and Operation (AECO) industry remains fragmented for the most part. It involves multiple specialties and organizations which adds complexity to the information exchange. Even when the use of BIM can contribute in making for a more efficient information exchange or interoperability, the lack of standardization on how the electronic information exchange is being conducted, still produces poor performance in exporting information from one authoring tool to another limiting the integration of design and construction information into the facilities management systems.

To-date, different approaches with different degree of success have been attempted to use BIM technology in the integration of information through the handover process. Some of these approaches consist of ad-hoc solutions, or implemented through somewhat non-open rigid commercial software solutions, or data specifications. However the general current interoperability issues including the lack of comprehensive development of open standards and the full support by software vendors to open standards still limit the full leverage that could be obtained through BIM technology for these purposes.

In addition, there is a mismatch between the needs for information of the FM staff needs and what is currently delivered by the design and construction professionals. It is not completely clear what information and at what level of detail should be included in the handover process.

Finally, the focus for the need of this information is currently conducted in the context of new construction whereas the majority of the demand for this information is coming from the large inventory of existing buildings. There is also a critical need for a methodology and BIM definition that supports the rapid creation of BIM for the existing buildings.

3 Methodology

In order to address the needs identified in section 2.7 of the previous chapter the following research objectives were identified:

- Identify the information that should be integrated into the BIM Model which will be of use for the FM staff.
- Identify the value of using BIM in the handover process.
- Develop an approach for integrating and maintaining this information available and usable by the FM staff.

These objectives were attained by following the next major methodological steps:

- Conduct an in depth Case Study of the facilities management process
- Identify the value and challenges of using BIM for FM
- Develop a proposal for a BIM-Enabled Digital Handover Process
- Validate the contributions of the proposed BIM-Enabled Digital Handover Process

3.1 Conduct a case study on the facilities management process

One of the key elements to propose a suitable BIM-enabled digital handover process is to have a good understanding of the facility management process, for this reason, an in-depth case study, consisting of two major parts was conducted with the support of the Facilities Department at WPI

The first part of this case study analyzed the Facilities Department organization and identified the main activities conducted by the department. To facilitate this task, access to the organizational chart and close interaction with the top staff of the departments was granted. A great learning opportunity emerged during this interaction because at the time of the study the department was migrating its Computer-Aided Facility Management (CAFM) system from one commercial software application to another. This situation made possible to participate as an observer during the implementation meetings and training sessions, the results and observations from this activity are presented in the section 4.1. The main goal of this part was to identify the information requirements of the CAFM.

The second part of the case study was conducted during the design and construction of the WPI Recreational and Sport Center, a facility completed in 2012. The case study consisted on analyzing the BIM models created by the architect and construction manager for the design documentation and 3D mechanical coordination as well as the close-out information delivered during the handover process for the Recreational and Sport Center building. This information was used to determine the properties, categories, structure and format of the information contained in the handover. The results of this part of the case study are presented in section 4.2. The main purpose of this task was to identify what is the information delivered at the end of the project, as well as its suitability for its later use, during the operation and maintenance stage.

3.2 Identify the value and challenges of using BIM for FM

The use of BIM for FM can have a wide range of applications, for that reason and for the purposes of this research it was necessary to determine where does the use of BIM to support the FM process that offers more value to the FM staff. This determination allowed focusing the efforts of this research. This research activity was accomplished by analyzing how the BIM models of two existing buildings on campus could best facilitate the space management of these buildings.

This activity was strongly supported by the WPI's Facilities Department. The two selected buildings were the Project Center and the Salisbury Laboratories. The Project Center building, is a relatively small-size and low-complexity office building, considered to be ideal for the purpose of defining a methodology for the creation of BIM models of existing facilities and for testing the functionality of the models in the integration of space management information. The Salisbury Laboratories building is a larger building with medium complexity; it accommodates office, classroom and laboratory spaces including a greenhouse. Applying the methodology developed for the Project Center building in the development of model for the Salisbury Labs building allowed to consolidate the methodology for BIM model development of existing buildings and to better understand the implications of the use of these models for space management purposes. The results are discussed in section 5.1

3.3 Develop a proposal for a BIM-Enabled Digital Handover Process

The BIM Planning Guide for Facility Owners, maintained by Pennsylvania State University (Computer Integrated Construction Research Program, 2012), is an outstanding set of documents to develop strategic, organizational, execution and procurement plans for the BIM implementation. It allows to asses existing organization conditions; align BIM goals and vision; develop a transition plan to implement BIM; plan a detailed implementation within the operations of the organization and; identify key issues for contract requirements. However this document focuses primarily on the organizational level from the owner perspective. The BIM Project Execution Planning Guide (Computer Integrated Construction Research Program, 2010), which is now part of the BIM Planning Guide for Facility Owner, focuses on maximizing the value of BIM from the perspective of the project team. The purpose of these guidelines is not to provide the detail for a specific use of the BIM, therefore when following this guide, as part of the implementation process, some more specific, technical and model-related questions need to answered such as, what building element to include in the model? What information needs to be attached to those elements? What is the proper Level of Development (LOD) of the deliverable? These questions, in the case of facilities management do not have a definitive answer yet. This research intends to provide that answer.

Different approaches exist to help answering these questions. COBie, is the most commonly known approach to-date (see section 2.5). However, even COBie does not provide enough technical detail on how to proceed beyond the point in which the main information is captured and delivered using spreadsheets that are not easy to produce. However COBie is based in a subset of the IFC´s Basic-FM handover definition that provides a starting point to develop robust model view definition that can be used as basis to check the deliverable's compliance.

This research proposes an approach that complements and extends the level of technical detail not covered in the scope of the BIM Planning Guide for Facility Owners.

Even when it can be an alternative to COBie, it can also be a complement to facilitate and improve the COBie data gathering process, and if desired be able to produce the COBie spreadsheets, since most of the information for such purpose will be available. This approach proposes to integrate additional information not specified in the COBie definition, however deemed valuable for the facilities management process. It focuses in delivering a BIM with the information needed for facilities management in it, and prepared to be used for supporting some of the facilities management sub-processes as a complement to the existing CAFM or CMMS.

The approach for a BIM-enabled handover process proposes to deliver the model as a part of the handover to the owner and transferring the responsibility to the FM staff for extracting the information needed for populating their CAFM systems. Under this approach, the responsibility for extracting the information relies on the FM staff. Relying on the completeness, integrity of the information contained in the BIM and seamless transfer it to the CAFM implies a high risk. For this scenario to succeed the verification of the completeness, integrity and format of the information included in the BIM needs to be assured. In addition the BIM currently does not include all the information the FM staff needs. There is not reliable software solution that guarantees a successful transference of the information from a BIM to a CAFM. It is possible to query the BIM by using third party tool and then copy this information into the CAFM but this process is likely to be equally or more time-consuming process than re-typing the information from a printed paper document.

For structuring the proposal the Information Delivery Manual (IDM) approach (Building Smart International 2010c) was used, it provides detailed specifications of the information to be included in the handover. Such specifications are implemented in the BIM through the Model View Definition (MVD). The MVD is a technical structure that formalizes the user requirements for the information handover process (Gobbler 2010). It is, documented in a way that enables the activation of current exchange capabilities of the BIM authoring tool.

IDM is a methodology that can break down a model into smaller, useful but still related parts. The set of information contained in each part needs to be exchanged to support a particular business requirement and must be established. This is called "exchange requirement". An exchange requirement is intended to provide a description of the information in non-technical terms. The technical content required to support an exchange requirement is provided as a series of functional parts of the Model View Definition. A functional part is a consistent set of units of information or concepts.

IDM is intended to be a methodology by which users can use the BIM software tools for information exchange solutions that meets their daily process needs, within the overall framework of an extensive, consistent and well tested information schema, such as the IFC.

The approach is discussed and presented in the form of an IDM with its MVD and is documented in section 6.

3.4 Validate the contributions of the proposed BIM-Enabled Digital Handover Process

For the purposes of technical feasibility and reliability, the handover approach proposed in this research needs to be validated. For this research validation was done in two parts. The first part conducted an online survey distributed to facilities management staff collected information through personal interviews with selected facilities management executive staff of colleges in the local area this is discussed in section 5.4. The second part validates the technical feasibility, it consisted in creating a proof of concept by applying the proposed approach to the model used for the Recreation and Sports Center model, using BIM authoring software, a model version for the handover was created, this is discussed in detail in section 6.3.

4 The facilities management process

In order to provide a suitable approach, the FM process must be understood, for such purpose a case study was conducted with the support of the Facilities department of the WPI, whom provided access to meetings, interviews and documentation. The case study consisted in three aspects of the facilities management process, 1) the study of the facilities department, its organization and main functions; 2) the analysis of the current handover process and; 3) a proof of concept on utilizing BIM for space management.

The current section describes part 1 and 2 of the case, section 5 discusses part 3.

4.1 The facilities department

The first part of the case study is a general view of the department, then the discussion is narrowed on the tasks the department perform in a regular basis, focused on the information they need to support the day to day work.

4.1.1 Organization

Worcester Polytechnic Institute was founded in 1865, currently the campus is formed by 105 buildings including academic, office, sports, parking and dormitory facilities. The campus is located in an 80 acres single site in an urban context at the city of Worcester. WPI is a private institution, with an enrollment of 4,012 undergraduate and 1,916 graduate students, and 478 Faculty members.

> *"The mission of the Facilities Department is to provide a safe, clean, properly maintained environment for the WPI community, in support of academic and social activities. Facilities staff will furnish the highest quality service, with the highest level of professionalism."* (WPI 2014)

The mission statement remarks the main functions of the department and also demonstrates a commitment with the main function of the WPI that is to educate talented man and woman in preparation for career of professional practice.

The department has 42 members, as of the date of this research, it has four major areas (see figure 11),

- Environmental and Occupational Safety
- Project Management and Engineering
- Facilities Operation
- Facilities Systems,

The Environment and Occupational Safety area provide the services for the protection and promotion of a safe learning, living and working environment, it offers the following main services, Employee accident report tracking; Lab safety training; Materials safety; Hazardous waste management.

Project Management and Engineering is the area of the Facilities department in charge of managing the renovations and new construction projects.

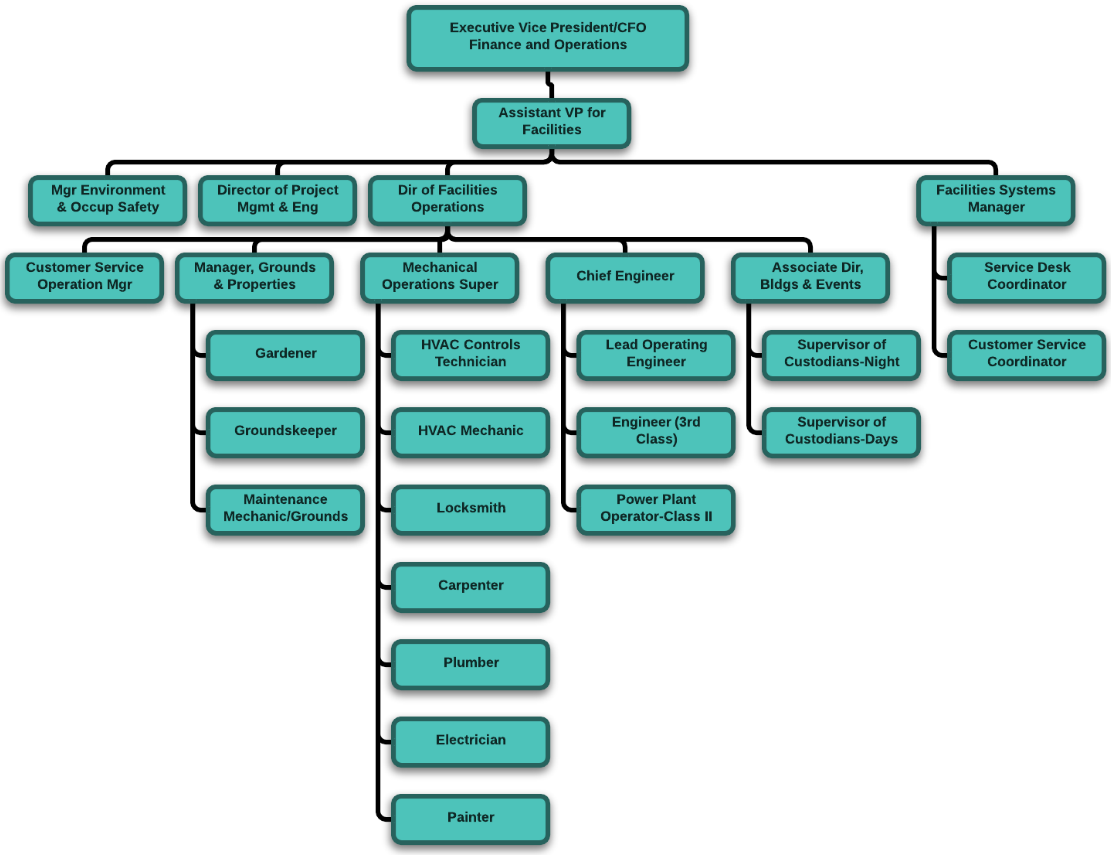

Figure 11 Facilities Department Organization Chart

Facilities Operation is in charge of the maintenance of the facilities and its systems for the optimal operation, is the most resource demanding function of the department and where most of the personal is allocated. This area is divided in four major categories:

- Grounds and Properties, is in charge of maintain a safe and attractive outdoor environment, including landscape, parking lots, driveways and walkways, one major task for this is the snow removal during winter season.
- Mechanical and Operations, is in charge of the preventive and reactive maintenance of the HVAC, electrical, plumbing and carpentry systems of the campus buildings, including the door key distribution and control for the mechanical locks.
- Engineering, are mostly in charge of the power and heating plants of the campus.
- Building and events, in charge of the custodial service for provide cleanliness; also support the spaces set-up for academic, sports and special events.

Facilities Systems is in charge of managing the Computer Aided Facilities Management System (CAFM) and Computerized Maintenance Managing Systems (CMMS) of the institution, it is also the main contact for any request through the Customer Service Center. It receives the request from the users and route instruction to the proper staff for servicing the request.

Currently the facilities department do not have a formal space management policy, even when they need information regarding spaces, such as room area quantities for custodial allocation; or for hiring floor cleaning and maintenance services, of for supporting research grants application where the area of research, classrooms and other types of facilities is needed; for evaluating the ROI by department and; for operation permits/license and certification among others, the common practice is they calculate this information as they need it.

Another important task of the facilities department is to advise and support the decision for invest in new projects to satisfy the growing need of the institution, for this task the facilities department uses the a Facilities Condition Assessment report that was created on 2011 and Space Management information calculated from the available building drawings.

The department recently made an improvement to their CAFM, they move from a desktop application to a cloud-based application, this allow their users to access directly to the system for creating a request, they use the system to route the request to the staff whom will be on charge to service the request.

The set-up and migration from the previous CAFM system to the new one made the Facilities staff to review their facilities process and was a great opportunity to study this process as this research was in progress at the moment when the migration tool place.

4.1.2 Computer Aided Facilities Management (CAFM)

WPI was using a popular and widely used software for supporting the Facilities Management process and in June 2013 started migration to a more specialized software solution. The software they choose is a complete solution created specifically for schools and universities and is a modularized system. WPI decided to use only three modules of the system considering that this covers their main processes: preventive maintenance, reactive maintenance and inventory management. They decided to start with the implementation of the reactive maintenance module, once this was ready and operating they continued with the preventive maintenance module, which as of the date of this report, is still in the process of implementation, in the near future they will start implementation of the inventory management module.

Observing the implementation of the new CAFM was very enlightening regarding the information needed to operate the systems, even when each CAFM system operates different, there is always core information common for a typical CAFM system. For this case the information related with the physical facility is organized as follows:

At the top level is the location which refers to the physical extent of the campus, if the university has multiple campuses, each campus is a location. A single campus can be divided into sections, in such case each section will be a location.

The next level of information is for the physical facilities, or built environment, it includes the buildings and grounds that composes the campus.

The next level includes the vertical and horizontal division of the buildings and grounds, including zones, floors and rooms.

The following level in the information hierarchy is the system which can be located in any of the levels of the vertical and horizontal divisions of the facility.

The last level contains the items which composes the system.

The four levels of hierarchy (see figure 12) of the information described above, conforms the core information needed from the physical facility for the case of the inventory and reactive maintenance modules (see figure 12). Each of the items included in each level in the organization includes a set of properties or parameters that are helpful for decision-making and those are discussed at the end of this chapter in section 6.

In the case of preventive maintenance an extra layer of information is required because it is based on the current conditions of the component of the facility. Schedules of actions regarding the maintenance needs to be clearly defined and managed, for this case WPI is defining the main systems and the maintenance procedures for each system (see figure 12), this accompanied of the current conditions define each schedule of preventive maintenance.

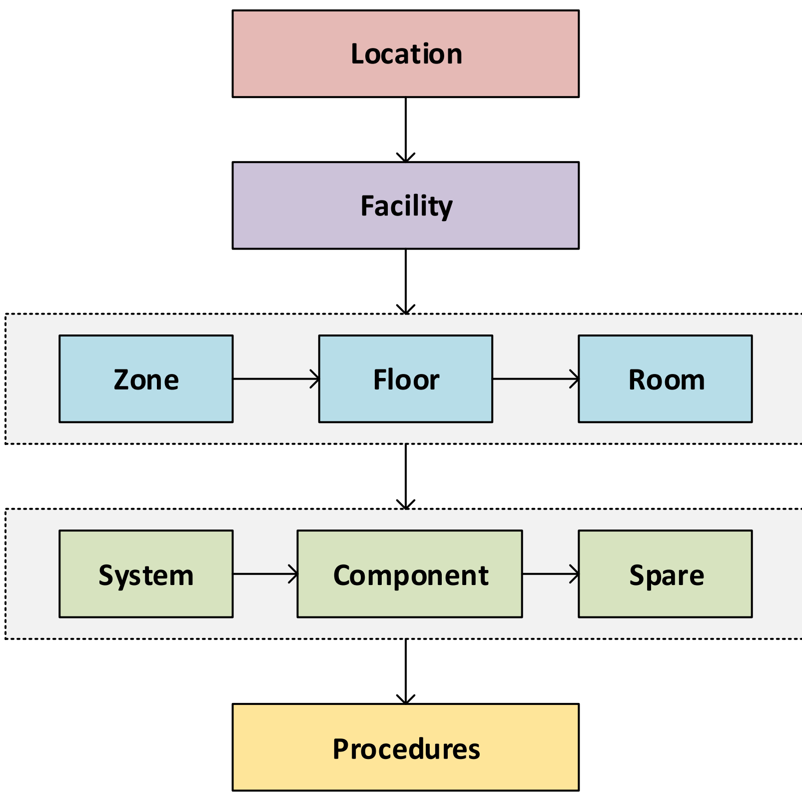

Figure 12 FM Information Hierarchy at WPI

Critical information was revealed during the meetings of implementation of the system, such as, the location awareness of the elements is very important as it defines the safety measures, the best time for doing job, the set of keys needed to access the items to be served, among others. The planning of the maintenance is strongly relied on the location of the item. Accurate and richer information of the item to be maintained and its location produces reliable maintenance plans.

The information about the condition of the system and its components, if the facility is new, comes from the main contractor through the handover information package, if the facility is not new, it should come from previous maintenance and assessment reports.

Maintenance is the main function of the Facility department, at least, the more resource demanding activity, however another important and evident function of the department is the space management, which is not part of the current CAFM but as a part of this research and the facilities department interest a pilot project was developed and is discussed on section 5.2.

Reactive maintenance is the only module of the CAFM that is in full operation as of the time of this research, preventive maintenance, inventory management and space management are carried out mostly by manual methods using spreadsheets, and building drawings.

4.1.2.1 Maintenance data analysis

Analysis of the data in the maintenance module of the CAFM system was conducted to have a clear idea of where are the resource focused and prioritize the information that supports such tasks.

The current system started operation on July 2013 and the period analyzed goes from that date until March 2014, the raw data were exported to a coma separated file, due the large set of records in the file direct manipulation was not possible and was analyzed using the OLAP cube functionality in Microsoft Excel®.

The first part of the analysis was made to find out what are the main type of work, measured with two parameters, the cost and the number of work orders.

Figure 13 shows the type of work sorted by the percentage of total cost for the maintenance of the facilities. It is very clear that most of the cost is on five trades, HVAC, Carpentry, Electrical, Plumbing and Key and Lock, which account for 87% of the total cost incurred by reactive maintenance in the nine months registered in the CAFM system. HVAC is by far the most costly maintenance trade. The labor costs are slightly greater than the materials required in the maintenance.

Figure 14 shows, the trades sorted in accordance to the number of work orders, the same five trades appears first, however the order is different, key and locks are the trade with more work orders (1,382). There is a confirmation that this five trades accounts for approximately 90% of the cost and number of requirements.

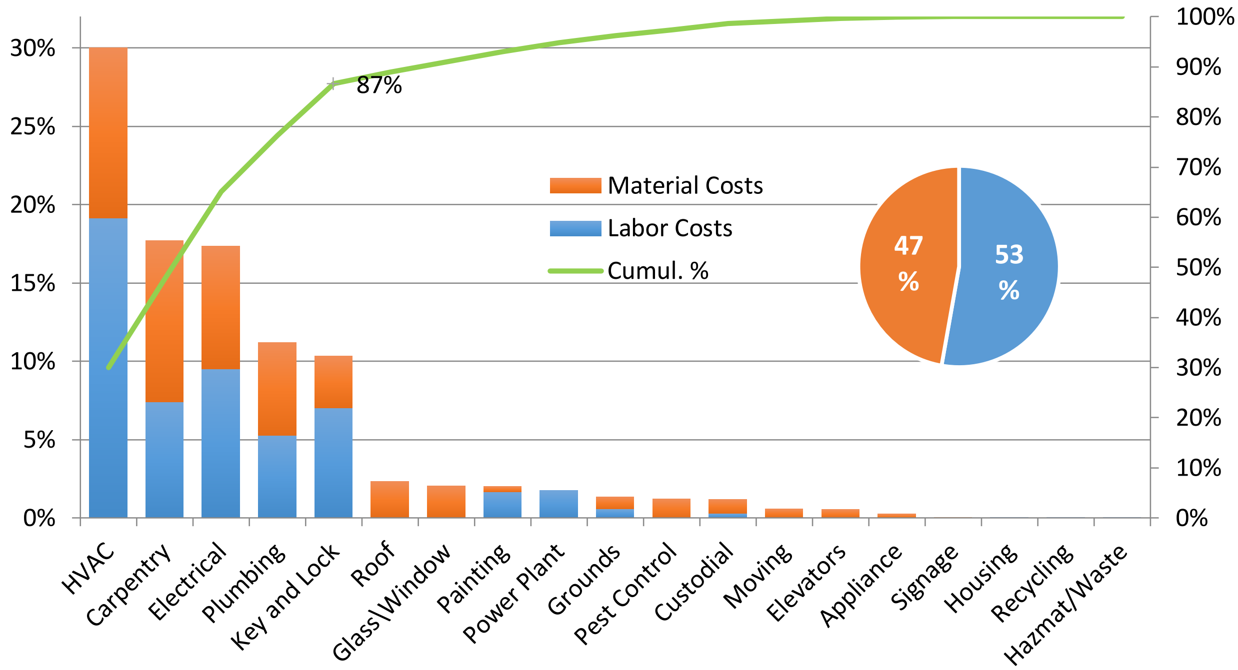

Figure 13 Type of reactive maintenance by cost

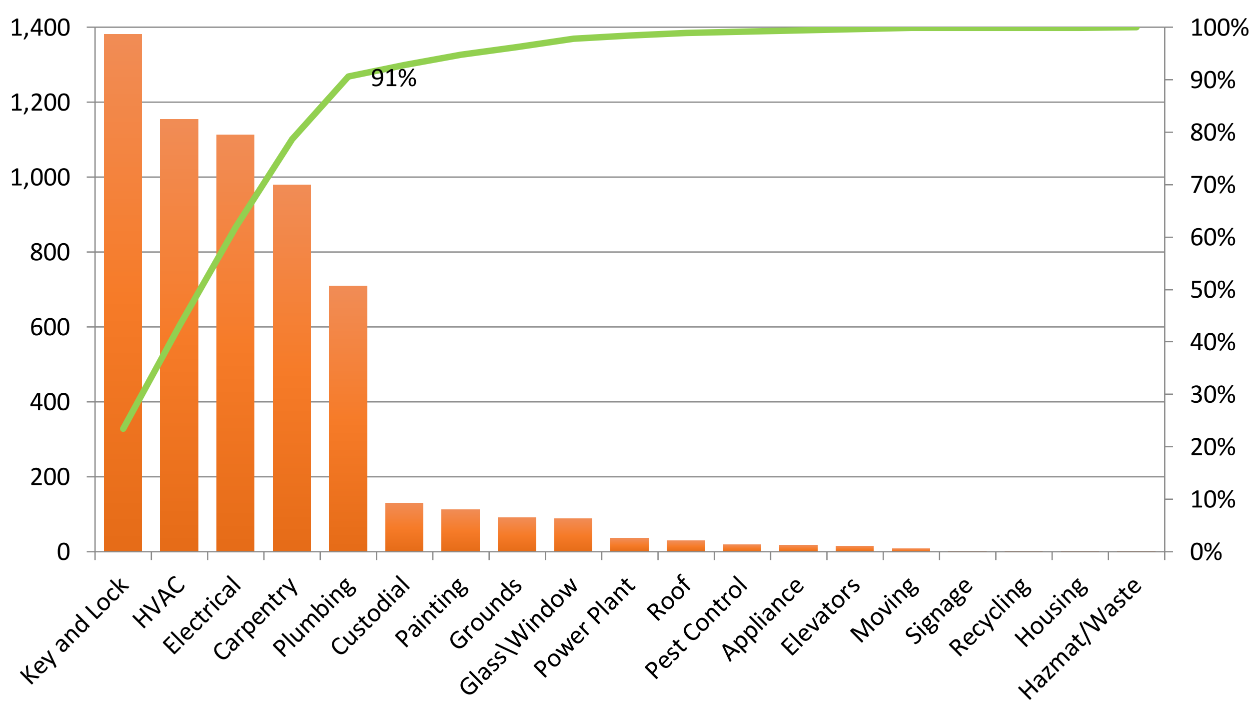

Figure 14 Type of reactive maintenance by W.O. count

Focus on the five most important trades from the first analysis, a breakdown of the contribution of each building in the campus to those trades were conducted, for both the cost and the number of work orders.

Table 2 Buildings contribution to maintenance cost

Row Labels	Carpentry	Electrical	HVAC	Key and Lock	Plumbing	Grand Total
Gateway 1	1.21%	1.54%	3.25%	0.76%	0.31%	7.07%
Recreation Center	1.34%	1.23%	1.76%	0.30%	0.71%	5.34%
Daniels Hall	2.42%	1.00%	0.84%	0.35%	0.68%	5.28%
Higgins Labs	0.79%	0.80%	2.48%	0.66%	0.34%	5.07%
Goddard Hall	0.39%	0.85%	2.23%	0.61%	0.63%	4.72%
Washburn Shops & Labs	0.35%	0.60%	1.71%	0.71%	0.74%	4.11%
Faraday Hall	0.64%	1.27%	0.61%	1.09%	0.22%	3.83%
East Hall	0.59%	0.46%	1.40%	0.36%	1.01%	3.82%
Atwater Kent	0.20%	0.77%	0.53%	1.44%	0.43%	3.37%
WPI Campus	0.05%	0.68%	1.63%	0.17%	0.41%	2.94%
Salisbury Labs	0.73%	0.55%	0.95%	0.29%	0.36%	2.88%
Fuller Labs	1.09%	0.20%	0.78%	0.63%	0.07%	2.77%
Institute Hall	0.23%	0.17%	0.66%	0.13%	1.46%	2.65%
Alden Hall	0.14%	0.54%	1.06%	0.46%	0.42%	2.61%
Morgan Hall	0.94%	0.33%	0.69%	0.26%	0.37%	2.58%
Morgan Hall Dining	0.43%	0.09%	1.57%	0.02%	0.32%	2.43%
Campus Center	0.63%	0.68%	0.41%	0.51%	0.18%	2.41%
Gordon Library	0.50%	0.44%	0.97%	0.09%	0.23%	2.23%
Founders Hall	0.21%	0.26%	0.87%	0.26%	0.50%	2.10%
Founders Hall Dining & Outtakes	0.03%	0.12%	1.56%	0.03%	0.10%	1.83%
Boynton Hall	0.59%	0.56%	0.28%	0.18%	0.20%	1.82%
Harrington Auditorium	0.22%	0.56%	0.62%	0.19%	0.06%	1.66%
Stratton Hall	0.37%	0.26%	0.66%	0.15%	0.08%	1.52%
Kaven Hall	0.09%	0.56%	0.56%	0.18%	0.05%	1.45%
Campus Center Dining	0.28%	0.40%	0.29%	0.11%	0.34%	1.41%
37 Lee St	0.69%	0.34%	0.11%	0.24%	0.01%	1.39%
Ellsworth Apts 1-5	1.06%	0.03%	0.00%	0.03%	0.20%	1.32%
Olin Hall	0.19%	0.18%	0.40%	0.28%	0.13%	1.19%
Bartlett Center	0.08%	0.20%	0.59%	0.10%	0.03%	1.00%
Sanford Riley Hall	0.18%	0.32%	0.20%	0.15%	0.12%	0.96%
25 Trowbridge Rd.	0.12%	0.09%	0.60%	0.03%	0.04%	0.88%
Project Center	0.17%	0.07%	0.52%	0.08%	0.03%	0.87%
Powerhouse	0.03%	0.00%	0.79%	0.02%	0.02%	0.86%
Alumni Gym	0.44%	0.25%	0.04%	0.04%	0.09%	0.85%
Higgins House	0.28%	0.27%	0.12%	0.06%	0.08%	0.80%
Fuller Upper Apts 1-14	0.11%	0.45%	0.00%	0.05%	0.13%	0.74%
20 Schussler Rd.	0.01%	0.06%	0.62%	0.00%	0.01%	0.70%
10 Hackfeld Rd.	0.50%	0.01%	0.02%	0.00%	0.00%	0.53%

Table 2, shows the 38 of the 99 buildings that accounts for the 90% of the maintenance cost, the yellow bars represent the proportion of the trade for that building in relation to bar in the Grand Total column.

Table 3 shows the number of work orders, from the point of view of this parameter, 39 of the 99 buildings account for the 90% of the total work orders count.

Table 3 Contribution of the buildings to work orders count

Row Labels	Carpentry	Electrical	HVAC	Key and Lock	Plumbing	Grand Total
Higgins Labs	53	42	75	110	20	300
Recreation Center	78	47	73	50	51	299
Goddard Hall	28	29	83	124	31	295
Washburn Shops & Labs	19	47	51	143	23	283
Gateway 1	40	43	95	48	22	248
Campus Center	50	42	25	99	21	237
East Hall	25	42	44	31	77	219
Fuller Labs	29	31	34	101	7	202
Daniels Hall	45	58	34	23	27	187
Salisbury Labs	33	36	43	53	16	181
Atwater Kent	21	29	36	75	14	175
Morgan Hall	50	23	37	20	25	155
Faraday Hall	32	50	34	21	15	152
Founders Hall	24	36	24	31	36	151
Alden Hall	19	13	23	82	7	144
Boynton Hall	46	30	22	19	10	127
Olin Hall	17	20	19	46	14	116
Morgan Hall Dining	27	12	52	2	19	112
Gordon Library	26	34	25	11	15	111
Campus Center Dining	15	24	16	18	21	94
Sanford Riley Hall	22	22	19	10	21	94
Kaven Hall	13	30	15	29	7	94
37 Lee St	29	15	4	34	4	86
Harrington Auditorium	17	27	20	17	4	85
Stratton Hall	17	10	19	31	6	83
Institute Hall	11	15	11	11	7	55
Higgins House	8	21	10	8	4	51
Fuller Upper Apts 1-14	10	24		3	14	51
Project Center	12	6	22	7	3	50
Bartlett Center	7	14	18	8	3	50
WPI Campus	4	21	18	2	5	50
Stoddard A	5	15	3	6	15	44
Stoddard B	15	15		8	6	44
Founders Hall Dining & Outtakes	3	5	16	2	14	40
25 Trowbridge Rd.	11	7	9	3	5	35
35/37 Institute Rd.	8	6	7	9	4	34
Stoddard C	4	13	1	4	7	29
Garage - Park Avenue	2	3	6	14	3	28
Fuller Lower Apts 15-26	5	10		4	8	27

The figure 15 shows the graph of the cost and W.O. Count of all the facilities in the campus included grounds, grouped by type of facility. In it is clear that the buildings related with the main activity of the organization are the ones demanding more maintenance. The red dot in the chart correspond to the W.O. count for each type of facility, its values are in the right vertical axis.

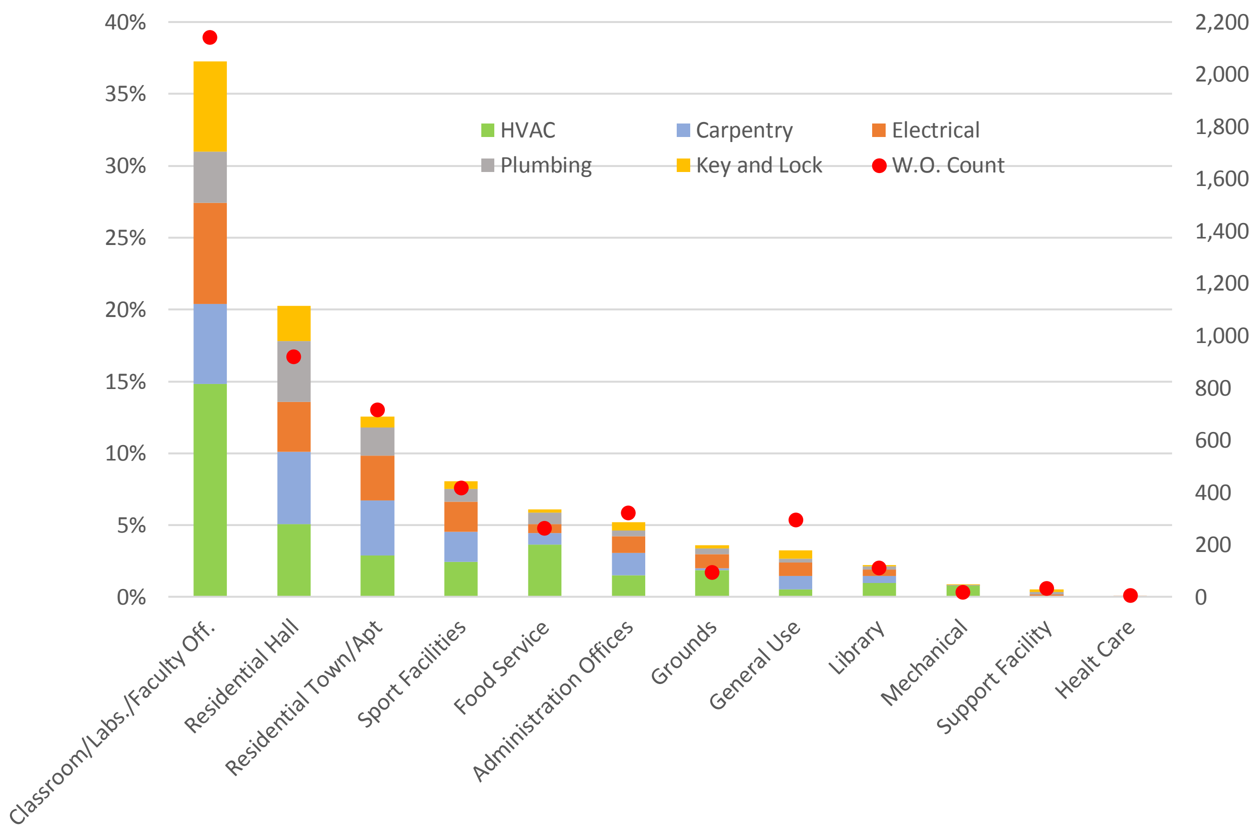

Figure 15 Cost and W.O. Count by type of building

This data includes preventive and reactive maintenance information, even when the module for preventive maintenance is still in the implementation stage, the FM staff did use the reactive maintenance module for generating the proper work orders for preventive maintenance.

4.1.3 Conclusion

The conclusion from this part of the case study is that there are five mayor types of work that accounts for approximately the 90% of the total cost and number of work orders. The type are:

- HVAC
- Carpentry
- Plumbing
- Electricity
- Key and Lock

This mayor categories applies for all the type of buildings, however, classrooms/Labs/Faculty Offices, and Residential accounts for 70% of the total cost and work orders. It is common in the university campuses to find building that host Classrooms, Laboratories and Faculty Offices, this is where the main function of a university takes place, and the type of facility that accounts for almost 40% of the total cost of maintenance and work orders count.

This fact directly relate with the first objective of the thesis that is to find out what information is needed to be delivered. This five categories account for approximate the 90% of the cost of the maintenance, same on the work orders account. These categories should be prioritized among the information delivered at the end of construction. If a building type should be prioritized that would be in the order of the chart in figure 15 above.

4.2 The handover process

The objective of this case study is to analyze what information is included in a typical handover package, as well as to identify the format and structure of the information. A recently constructed facility on the WPI campus was selected for this case study because of its level of complexity and the handover process took place at the time this research was developing.

One of the main goals of this section of the research is to identify the suitability of the information for its later use during the operation and maintenance. As was mentioned on section 2.2.2 the two main characteristic that gives usability and longevity are the structure and standard format of the information. The best information of this purpose is what is showed in the purple zone of the figure 16 below.

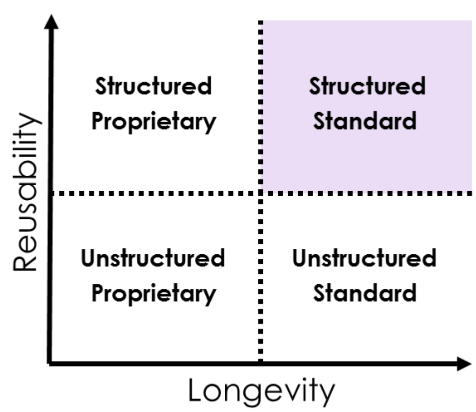

Figure 16 Best information for longevity and reusability

4.2.1 WPI Sports and Recreation Center

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

The facility started its construction on 2010 and begun operations on summer 2012 but it was until March 2013 that the handover process took place. The project delivery used for this facility was Design-Bid-Build.

The information handover was delivered by the main contractor through a data DVD with the information in digital format and organized by trades. The package included a total of 540 files.

Table 4 Summary of document in the Rec Center handover

Count of Link	**Column Labels**					
Row Labels	**DOC, DOCx (Word)**	**DWG, DXF (Autocad)**	**PDF (from digital)**	**PDF (from hard copy)**	**XLS (Excel)**	**Grand Total**
Drawing		92	160	2		254
General Information					1	1
Guarantee	1		2	1		4
Inspection	2		1	7		10
O&M Manual	1		40	51		92
Specifications	1		10	10	1	22
Warranty			17	42		59
Grand Total	**5**	**92**	**230**	**113**	**2**	**442**

A review of the content of the files was conducted to acquire more knowledge of the information included. A Microsoft Access database was created for this purpose and two main characteristics were analyzed for each document:

- The type of document contained in the file
- The format of the file.

In addition, the database included other information such as:

- Is information is structured? (yes/no)
- The link (URL address) to the WPI's SharePoint repository
- The status of the information (for construction or as-built)
- The overall result of this analysis is shown in the following table and chart.

From the 540 files contained in the package only 442 files contained useful information. 98 files where automatic backups of the files created by the software or files with some logos and schemes referenced inside other files.

Regarding the type of documents, it was found that more than the half of the files were drawings. On the format, most of the files are in the PDF format (See Figure 16)

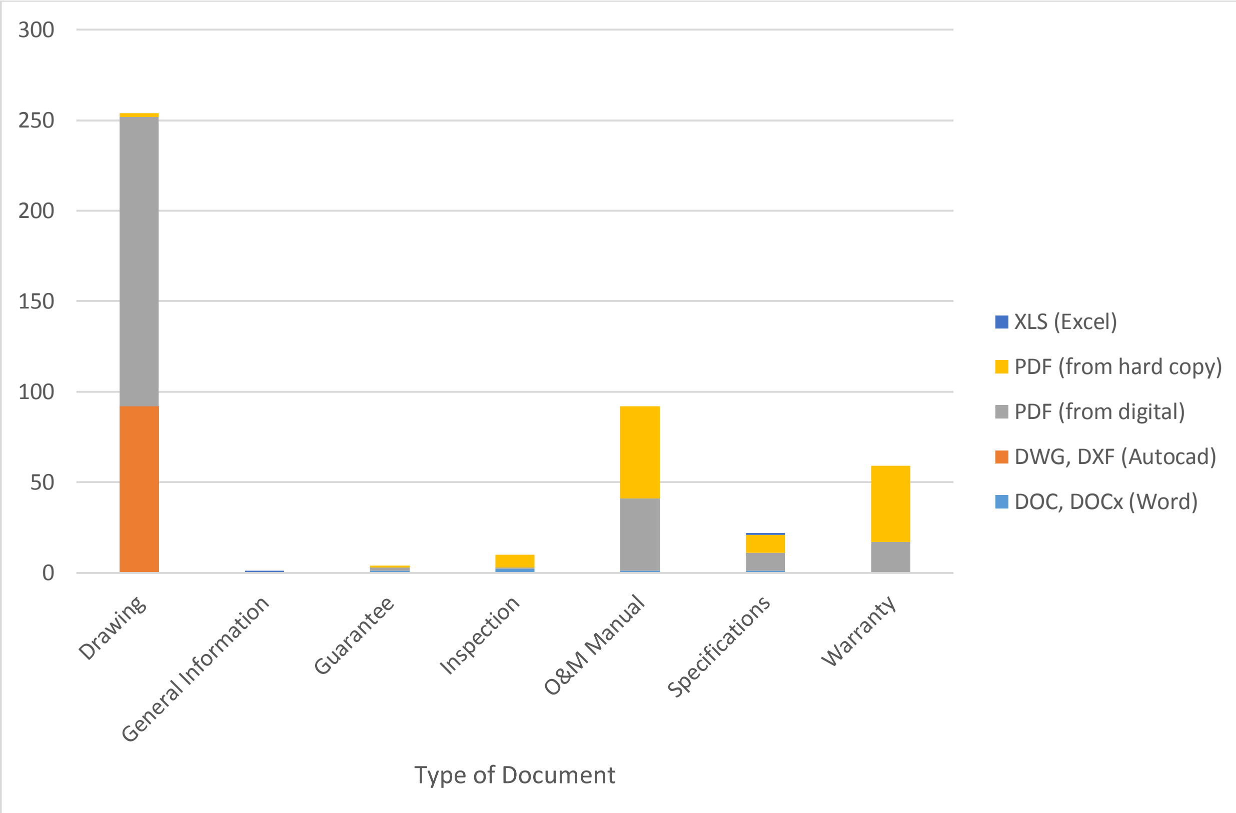

Figure 17 Types of document in the Rec Center handover

4.2.2 Documents categories analysis

Following is the detailed analysis for each type of document.

4.2.2.1 Drawings

254 of the files are drawings, 92 of them are CAD drawings which have also a PDF version of the file, which means there is redundancy in the information. This duplicity is not an issue it can be an advantage for the user because is easy and faster to open the PDF version of the file than the DWG. Having both versions allows the users a quick view of the information using the PDF version and the possibility to update the drawings if needed using the CAD version. However 59 drawings have only a PDF version and 2 are scans of a printed version which had a lower quality.

The status of the drawings is As-Built, and comprise Existing Conditions (before construction), HVAC, Plumbing, Electrical, and Fire Protection. The included As-Built has no indication that architectural or structural layout is the As-Built and since there is no architectural nor structural As-Built drawings included there is no way to verify if the reliability of the layout of the included As-Built drawings.

Room numbering and level naming has some inconsistencies between different trades.

Names of the files are a cryptic and very short; therefore there is no clear indication of what is included in the drawing. This issue will cause spending some extra time to find the required information when needed.

There is a case of a drawing which the title of the drawing indicates a wrong level number, this can lead to errors if not detected.

Even when a there is a number of drawings with structure (DWG format) the usability is limited to another CAD software not the CAFM software. Even when DWF and PDF are proprietary formats those are widely used and probably maintained during long time, however because of the nature of the information of this category and its use, it will become an obsolete way to deliver this kind of information, therefore the longevity and usability of this category are limited. See figure 18.

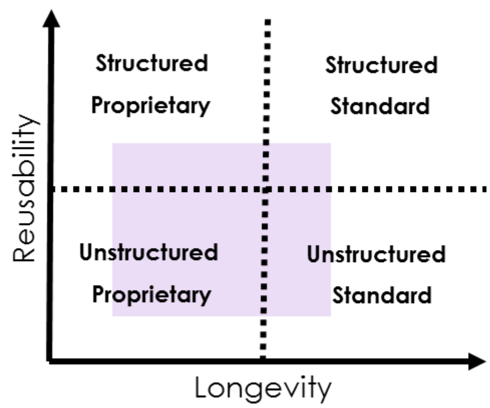

Figure 18 Longevity and reusability of the drawings

4.2.2.2 Operations and Maintenance (O&M) Manuals

This item is second with regards the number of files with 92 documents. 40 of them in PDF format from a digital document and 51 of them in PDF format product of a scanned printed document. The main advantage of a PDF from a digital source is that the content is searchable, which is a powerful feature because some documents have several pages. Another advantage is the quality of the text and graphs is better when the PDF came from a digital source. A PDF from a scanned hardcopy can be post-processed using Optical Character Recognition (OCR) software providing some functionality to the search engine, even though, nowadays OCR software results are acceptable, is not yet a 100% reliable because the quality of the scanned document affects the OCR results.

Many documents contain more than one equipment and are not reflected in the title. The vast majority of the documents that contains “multiple equipment” do not contain a table of content. This make a complex task to find the O&M instructions for a specific equipment, specially knowing that more than the half of documents are PDFs from hardcopy which lacks of text search capabilities.

Some equipment referenced in the O&M documents are not clearly referenced in the drawings. It will be hard for someone not familiar with the building to find the proper O&M instructions.

It was common to find warranty information in the same document that the O&M.

All of the documents are PDF format, many of them scanned versions of the paper-printed documents, and therefore all of the information contained is unstructured. PDF even a proprietary standard is widely used and likely to be maintained long time. The longevity and reusability of the information is showed on figure 19.

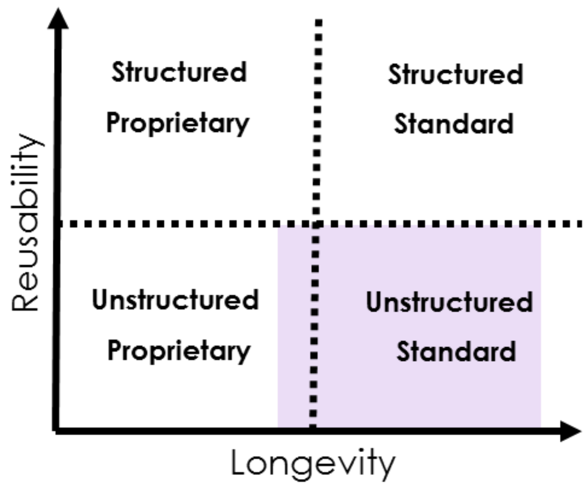

Figure 19 Reusability and longevity of O&M manuals, Specifications, and Warranties and Guaranties.

4.2.2.3 Specifications

Specifications contains technical information about the components of the building, many of this documents where developed for the construction phase because this kind of technical information is needed for assembly and installation. This information is also useful for O&M because it indirectly shows how to disassembly a building component if needed. Also, is common in this documents to find the list of spare and replacement parts for the O&M of the building components.

The analysis for the Operation and Maintenance Manuals category, just explained above, applies for this category. Even the proportion of PDF from digital and PDF from hardcopy is almost the same. The longevity and reusability of the information can be seen on figure 19 above.

4.2.2.4 Warranties and Guarantees.

This is an actionable document that protects the owner against defects on the materials and installation. 63 documents of this nature were included in the handover package.

For this category 43 documents were originated from a Hardcopy, which for this category is better because it contain information that is usually filled by hand, stamps, and signatures for validating the document. Even when this validation can be done digitally in the case of the PDF documents from a digital source not digital signature were found. This may cause some issues is the need to apply the warranty or guarantee is needed.

A PDF from a hard copy do not imply that the document validation information is there as is the case in some of the documents of this package.

The longevity and reusability of the information can be seen on figure 19 above.

4.2.2.5 Inspection

There is 10 documents which includes report from inspections made at the commissioning phase. Most of the documents are in the format of PDF from hardcopy with the proper validating signatures.

4.2.2.6 General Information Documents

In this category only one document was tagged. The document is a list of sub-contractor, installers, and providers for the HVAC system with its contact information in the Microsoft Excel format.

4.2.2.7 Conclusion

Having the documents in a digital media is better than having it in printed paper, it is always easier to print the documents if needed rather than scan the documents. The files can be organized in a shared folder and grant access to the users who need it.

For this case the approach of having the information available for the users through a shared folder requires to have in mind the following considerations:

- Naming the files according to a defined standard therefore the name became a descriptions of what is inside.
- Split documents that contain information into more than one equipment, the same for those who contain two or more type of documents as was frequent in the case of the O&M and Warranties.
- As a large number of documents are from a scanned hardcopy, weight the benefit of post-processing those documents through OCR software to allow searching the text inside the documents.
- If the shared folder or repository service where the document will reside, allows tagging of the documents, it is strongly recommendable to have a tag definition and tag the files. This metadata will increase in a significant way the usability of the information, this is the fastest way to find and retrieve information, the metadata or tags can give a clear idea of what is inside the document.

Storage of the information for later retrieval is not the only purpose of the handover, one of the main uses of this information is for setting up the computerized system for managing the inventory and maintenance. Regarding this the following consideration need to be take into account:

- Most of the information included in the files lacks of structure, this inhibit the possibility of populating the computerized systems in an automatic way. The lack of structure in the information denies the interoperability therefore the information need to be manually typed into the computerized systems, task that is time consuming and prone to errors.
- The information is atomized, multiple documents need to be used to configure a single item, for example:
    - Configuring an item in an inventory managing system will need the specifications document for the main characteristics, the warranty document for the dates of coverage and the drawings for the location.
    - Configuring the maintenance of equipment will need the inventory data; plus the maintenance procedure, tools and safety equipment from the O&M document and the drawing to know how to access the equipment.

- The information of the five major categories identified on the CAFM case study (see section 4.1.2.1), that supports the maintenance process are included in the handover, the main concern is that the information is not structured in a scanned PDF, therefore the retrieval of the information should be done in a manual fashion, with all the drawbacks this method implies.

5 The value and challenges of using BIM for FM

This section present the results of the research addressing the identification of the value of suing the BIM technology for the handover and the support of the facility management process during the operation and maintenance stage. This is an important step of the research as the value of applying the technology need to be clear to serve as an incentive for its implementation. This section discusses a pilot project using BIM for space management, and then discusses what the reaction of the FM staff was during the space management project; finally it presents the results of the interview and survey to validate the premises of this research.

5.1 Space management

Space Management is an activity that seems to be naturally supported by BIM, another part of the case study consisted on developing a pilot project to have a real experience of the benefits of using BIM for this purpose.

In BIM most of the models are created for the use during the lifecycle of a construction project, including operations and maintenance, however the actual situation is that if BIM is to be used for space management, most of the existing buildings do not have a BIM and the model will need to be created. For that reason in this case study the buildings selected were two already existing projects with no BIM ever created. Therefore a byproduct of this case study was a proposed methodology for creating the models of existing projects which is presented in Appendix A.

The facilities department of the WPI strongly supported the development of a proof of concept project using BIM for managing and reporting information on the space usage for the Project Center and Salisbury Labs buildings at WPI.

The Project Center and the Salisbury Labs building were selected due to their particular characteristics, the first one is a small and relatively low complexity building and the Salisbury Labs are somehow in the opposite, as it allocate several activities and is bigger with a more complex layout. In this way the use of BIM was tested in those two cases.

The project center is a small two-story building where students once learned how to cast machine parts from molten metal. Today the upper level is home to the administrative center for the WPI plan and the University's innovative, project-oriented undergraduate program. In the lower level is the Career Development Center, which helps students launch their careers, and the Cooperative Education Office, which helps them find co-op assignments with corporations.

Salisbury Labs, is WPI's third building, completed in 1898, it is home to the departments of Biology and Biotechnology, Biomedical Engineering, and Humanities and Arts. It allocates labs for molecular biology, animal and plant cell culture, fermentation, downstream processing, molecular genetics, invertebrate zoology and bioremediation. A greenhouse at the top of the building supports innovative work in plant physiology and biotechnology. There are also biomedical engineering laboratories for work on biosensors and instrumentation.

The attributes that linked to the spaces in the BIM were:

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

The strategy for developing the project was to start with the less complex building, that is the Project Center model, which was completed by December 2013, this allowed to have a better experience and feeling of the approach. In this way if adjustments are needed this were considered prior the conclusion of the second and more complex building (see figure 20).

Figure 20 Sample view of the Salisbury model

5.1.1 The process of creating the BIM for the selected buildings

The selected buildings, as was previously mentioned, already exist and no BIM model has ever been created for those. This section briefly describes the main task involved in creating the models and the detailed approach is included in the Appendix A

1. **Retrieve and digitize the drawings for the buildings**. For these particular cases, CAD drawings existed for the buildings. The files were imported into the BIM authoring tool and used as a starting point.
2. **Verification of the dimension of the available drawings**. The drawings was verified taking measurements in the actual facility, using a laser distance meter, photogrammetry and for the exterior point clouds from laser scanning were available and used.
3. **Creation of the model**. After verifying the dimensions of the drawings the model can be created, the level of development of the models are 200, it includes the geometry and basic information of the modeled elements. The model includes walls, floors, fenestrations, roofs and stairs. No mechanical, plumbing or electrical systems were modeled.
4. **Creation of the rooms**. For the models, the rooms were created representing the space enclosed by walls and floors. The space calculation was set to volume, therefore not only the area of the room is available but also the volume
5. **Attaching the information to the model rooms.** The information selected for this initial stage was integrated as properties of the room instances in the model. The information was gathered directly from the facility at the same time the dimension verification took place.
6. **Deploy the BIM.** A light-weight version of the file was created and distributed to the users. This version is not editable and only for viewing and interrogating the model.

In both of the selected buildings, differences between the available as-built drawings and the actual facility were found, mostly due renovations never updated in the drawings. The drawings are not the original as-built, those were constructed from the facility at some time in the past and the drawings presented some inconsistencies from one level to another. All this were corrected in the BIM.

5.1.2 The model parameters

The parameters attached to the rooms were selected because were of main interest of the staff participating in the project.

5.1.2.1 Room numbers

The room identification is the information that is of common use, for this case the room number is the main identification. The numbering system used was the WPI own system this is basically a three digit system with the floor number as the first digit, the other two digits were for the room in the floor. A room inside another room was identified with a letter after the room number. The drawings used for constructing, the model had the room numbers on it. Those numbers were verified with the door tags installed in the actual facility. Differences in the numbering were found between the as-built drawings and the actual numbers in the door tags.

Most of the systems in the FM were configured using the numbers in the drawing. One of the CAFM that uses the room numbering is the custodial coordination system, the room numbers in this system were also contrasted with the actual facility and it presented several differences. The custodial coordination system was updated with the information in the BIM.

5.1.2.2 Room area

The room area is one of the most used information for space management. It is used for custodial assignation, space assignation to staff and departments, for reporting spaces inventory for grant application, for allocating costs among others

Room area was calculated directly from the model using the rentable area calculation method, with the verified dimensions and was reported as a property of the room.

The room areas is also part of the CAFM system for coordinating the custodial the room area was contrasted with the system and differences were found, the areas in the custodial system were calculated using two measures taken directly from the rooms, therefore this calculation is a less-accurate approximation than the calculation from the BIM, due the fact that it was frequent to find rooms with irregular shapes. The areas in the CAFM system for custodial coordination were updated using the areas from the BIM.

5.1.2.3 Floor finishes

Floor finishes was another parameter selected to be included in the BIM, this information is mainly used by the custodial coordination system. This information is attached as a property of the room, regardless of the floor modeled, which for this case is a generic floor type. When in a room more than one type of floor finish was found, the predominant floor finish was reported as the type for that room. The alternatives to this situation can be: 1) report a type of floor that is mixed (i.e. 70% carpet + 30% wood); 2) create a separate layer of areas for each type of floor; and 3) model each floor finishes. For this case most of the rooms had single floor finish and in the few cases where the room had more than one floor finish, the predominant finish covered more than 90% of the surface.

5.1.2.4 Room use

The “room use” parameter is used for efficiency rating, capacity calculation, determining future needs among others. For this pilot project two uses categorization systems where implemented, the first one according to the WPI standard, which was gathered directly from the door tags, the second was the uses according to the Post-Secondary Facilities Inventory and Classification Manual (National Center for Educational Statistics, 2006). This parameter is commonly used in companion with the room area for efficiency rating and capacity calculation.

5.1.2.5 Department

The department to whom the room is assigned was another of the main requested parameters to be included in the BIM. This parameter is used for allocating costs and ROI analysis, used in conjunction with the room area. This information was gathered from the buildings directory.

5.1.3 Use of the model

The users of the model are the facilities staff and other administrative staff, therefore the usable model should not require great expertise for handling the model. The format and the tool for accessing and interrogating the model are the keys for a successful use of the model. One important factor that was taken into account is that the users preferred 2D representations of the model, instead of a 3D model;

they are very familiar with the 2D format and is a fact that the 3D model is good for visualization but for navigating and handling it, requires certain expertise in the use of the software tool. For that reason, the parameters were presented in the form of 2D colored thematic plan layouts, however those are interactive representation as the 2D elements are BIM instances with its properties, therefore can be interrogated,

To facilitate the use of the model a non-editable version was distributed, the format of the file was Autodesk DWFx, because It can be accessed using Autodesk Design Review®, which is a free viewer. DWFx files are small in size in relation to the original model file; therefore it can be easily distributed. For the current study the file was distributed through the school's Microsoft SharePoint® Service, and also using the Autodesk® 360 cloud service.

The DWFx can contain multiple predefined views, for this case each of the 2D thematic layouts for each level and parameter represented was included in the file, as well as a 3D complete model of the building, and a set of 2D floor plans with dimensions.

Three sessions of training on how to access and querying the model was conducted with FM staff and instruction material was created for future reference.

5.1.4 Maintenance of the model.

In the future, the model will need updating of the information and the model itself. The model should be updated when some renovation takes place. This should be done using the last version of the model and following the guidelines in Appendix A, then the DWFx version of the model shall be updated and redistributed. This kind of modification will not occur too often. Here is important to remark that having the BIM of the facility, will serve to perform the renovation, quantity take off and cost estimating; planning of construction strategy and sequence can be supported with the model, if this advantage is taken the updating of the model and the information will be a natural process.

The second modification the model will need will be on the information attached to the rooms, for doing this, the original model shall be accessed and the information changes done directly in the model. This will require some degree of proficiency in the use of the BIM authoring tool.

An additional tool was used and customized for the non-expert user who will maintain the information in a regular basis. The tool access and edit the attributes of the model through a Microsoft Access application, with a user friendly interface. In this way the model can be updated and redistributed.

Attaching additional parameters to the room can only be done using the BIM authoring tool, which requires certain degree of knowledge of the tool.

5.1.5 Conclusion

This part of the case study remarked the benefits of having BIM for space management, space is about the layout and geometry of the facility, BIM and the capability of 2D floor representation, color schemes and properties retrieval makes it suitable for this purpose.

The main attributes of the spaces required were clearly identified as well as how this can be used through the BIM utilizing a viewer software tool.

The facilities management staff embraced the technology, particularly where it was somehow familiar with what they are used to deal, this is the 2D representation of the facility, at the same time they welcome the new features such as the ability to retrieve information on the space.

The project was done on existing facilities and a method for creating the model was defined, tested and documented (see the Appendix A). In the literature review this kind of methodology was expressed as one of the needs for the adoption of BIM in the FM (Teicholtz 2013)

5.2 The value of using BIM for FM

The use of BIM for the handover and during the operation of a facility will bring some benefits for the FM staff, some of those are evident, another were possible to experience in the case studies, this section discusses the main benefits identified, particularly for the use of BIM at the construction stage,

The main tested use of BIM for the construction stage was for the space management, one of the main discoveries is that people who never handled a 3D model before, felt very comfortable using 2D version of the model, and experience the advantage of retrieving information from the objects represented in the model.

The visual representation of properties in the model, using color codes enhance the communication of the information in the BIM, give a new perspective to the users compared with a tabular report. Thematic floor plans representations are common for the FM staff; the method to create the thematic map is what BIM is enhancing, as those are created directly from the BIM. Even when the colored areas are the main feature of these representations, the doors, windows and walls are also in the layout and it can be interrogated for information retrieval.

When the results of this case study were presented to the FM staff they started to realize the potential of this technology, some of the suggestions they bring to the table were:

- Furniture layout options for multipurpose rooms, with 3D view capabilities.
- Include in the model equipment that requires maintenance, but rarely affected by renovation which would imply modification of the model, because of the model maintenance cost vs. benefit.
- Include in the model MEP elements for which the model representation does not require a high level of detail for a positive cost vs. benefit.
- For new buildings, it would be desirable to require the main contractor the delivery of a usable model for the FM, therefore a requirement specification needs to be defined.
- Integrate the single facility model in a model of the campus.
- Key codes as a property of the doors, for servicing Key replacement requirements.
- Routes to access the equipment to be maintained identifying the set of door keys to grant access to the location.
- Make the model available and include information for emergency response.

5.3 The challenges inherent in the using BIM for FM

During this research, challenges inherent to the use of BIM for FM were identified; those are discussed in this section.

5.3.1 The BIM software

The challenge with the BIM software is because it is majorly intended for the use of designers and contractors, even when software vendor states that their software is to support the whole facility life cycle the experience in this case study demonstrate that the functionality for the FM support is limited. The BIM authoring tools functionality focuses on the authoring task, not in the non-graphical information managing task. Viewer tools are intended to be used for the design review process, not for the use of the model during the operation and maintenance. New BIM tools are needed for the purpose of the facilities management, lightweight and versatility and non-graphical information editing capable should be characteristic of this tools.

BIM authoring software is complex, it requires certain level of proficiency to handle a BIM model, this imply that this capability needs to be present in the FM staff, for using the BIM authoring software to set up and maintaining the models, in addition, the cost of the BIM authoring software tools, needs to be taken into consideration. An alternative is asking the contractor to deliver the BIM model prepared for the use of FM and a usable version in an open format that allows to viewing and interrogating the model with open or proprietary viewers.

BIM software for the FM management is still in the early stages, software like Archibus®, FMSystems®, Onuma® and Ecodomus® are good tools but rather than a BIM software for FM those are CAFM or CMMS tools who are BIM compatible, that is the use of the BIM authoring tools is still needed to set up and maintain the BIM models. This kind of software is not complementary, those are complete CAFM solution for the owners and FM, therefore is not possible only to use the BIM part it is needed to implement the whole system, which may imply migrate from the current CAFM the organization uses to one of this new software solutions. This is always not an easy decision to take.

This type of software have an additional challenge, this is because those are compatible with BIM authoring tools, the developers are struggling keeping up with the BIM authoring tools whom updates their software each year with no backward compatibility. Sometimes vendors skip support for some yearly versions of the authoring software.

It is always preferable to have an integrated solution instead of two or more software for facilities management. This is not easy to achieve, as the complete solutions are for generic not for a specific type of organization, for example the WPI case, they have one system for the maintenance and assets inventory, another for custodial management, another for space reservation, and many other manual approaches for other purposes. This is because one software solution do not fit all the needs of the organization.

The current BIM software tools, maybe not the best solution for replacing a CAFM, rather it should be an extension for managing information where the physical representation and location awareness enhance the FM process, such as space management, or supporting the planning of preventive maintenance using the power of visualization of the BIM.

The BIM deployment tools are amazingly evolved, all of the mayor vendors of BIM authoring tools, have a good way to deploy BIM for the end users, most of this tools were originally created for the design review process, therefore there was the need to create software for integrating multiple formats of models, such models file had to be lightweight because the e-mail was the main way to deliver this information to the reviewers, characteristic that later allow the migration of this model to the cloud and mobile devices. This characteristic is great for the FM staff who spend many time of their shift out of their desks, and still be able to access the information through the BIM.

Is important to clarify that BIM is more than a collection of software tools, it also includes the organization and procedures to make the most of the models. FM usually have many systems for managing the information they need, BIM should not become another system, it rather take the role of regularize data delivery, clarify data ownership and facilitate data validation (Teicholtz 2013), and bring the power of data retrieval and visualization to the FM process.

5.3.2 The models

The model delivered after the project completion is very rich in information for FM, but not all of the information is valuable on a day to day basis within the broad functions of the FM department. Where data retrieval, change management and tracking cost and work on activities is critical (Teicholtz 2013). Usually the BIM used during the project design and construction is a mixture of 3D models, raster images, CAD drawings, point clouds and so on. Deliver the model this way may cause the model be of no use for the FM staff, therefore a final version of the model should be prepared.

In section 4 was discussed the five main activities that account for almost 90 percent of the total workload, related to the maintenance of a facility. And in this section the value of BIM for space management were also discussed. The model should be prepared to support those activities.

The level of development for a model that should be used for FM is 500, as is specified by the AIA (AIA, 2013), however the level of detail common for the level of development 350, and 400 is not required. This is a paradox, but a high level of detail will bring complexity to the model that is not required for FM. A model suitable for FM will require precise dimensions, of the walls, floors, levels, doors and windows. Precise location of MEP equipment, but the level of detail of the graphical representation of such element, is not required to be greater than the level of detail inherent to models of LOD 350 or 400. This is not meaning that the model should be downgraded, if an effort was done for giving the model an LOD of 350 and 400, it should be preserved, but preparation of model views filtering out elements and information used only for the purposes of design and construction should be done in the model delivered.

One key element of the BIM is the dimensional accuracy with the built facility as many decision of the FM staff are relying in the accuracy of the dimensions. As-built drawings are usually required as part of the handover, the as-built model should also be required with the proper verification and status update, making clear what parts of the model are actually as-built verified.

FM are used to deal with 2D representations, and for most of the purposes of the FM staff this should be the way the BIM be deployed to them.

Navigate a 3D model is not an easy skill, preparation of the 3D representations should also be defined in advance. Cut planes, transparency, color should be used to prepare defined views of the 3D model. Selection sets for the different systems of the building should also be prepared; therefore the final user can easily turn on and off those layers for easy viewing of what he needs.

5.4 Applicability validation

The approach herein proposed is based in the findings from the case studies conducted in this research and in the literature review. To validate and determine the general applicability that these findings offer as a fundamental contribution to the state-of-the-art that an interview with selected facilities management executive staff and an online survey was created and distributed to 121 individuals or organizations managing colleges and universities who attended to the SCUP regional conference in Boston on march 2014. The general validation strategy is shown in Figure 21 and the details of this survey are shown Appendix E.

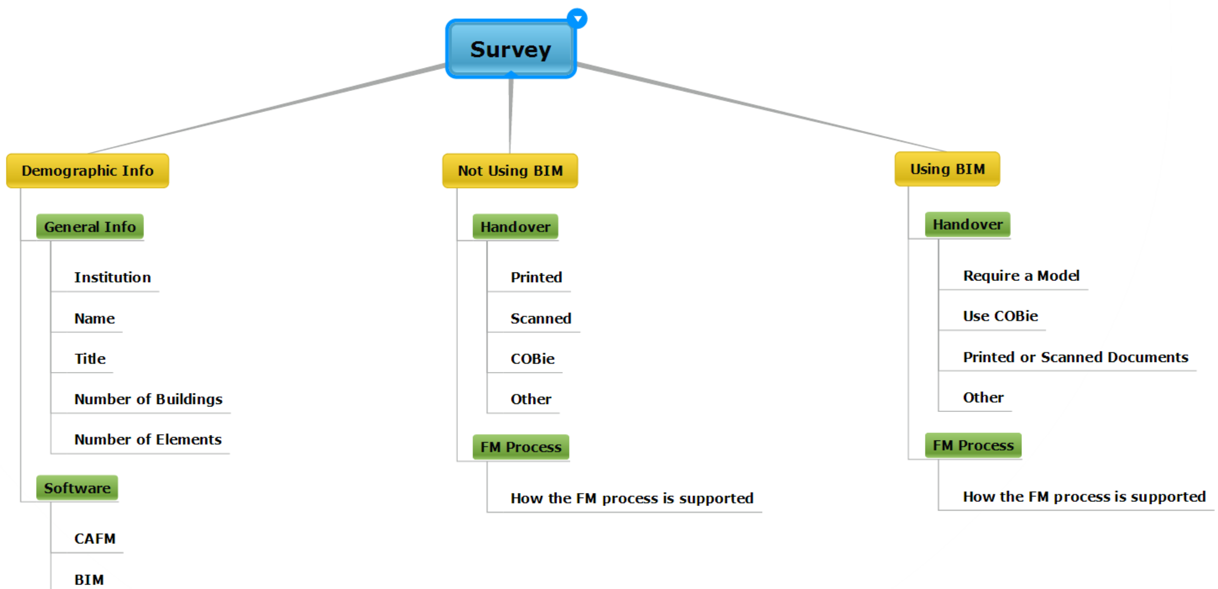

Figure 21 Structure of the survey

5.4.1 Interview

A personal interview was conducted on July 23th 2014 with John T. Baker, Associate Vice Chancellor for Facilities Management of University of Massachusetts Medical School, Worcester Campus. He was selected because his leadership in the implementation of BIM for the handover of the Albert Sherman Center discussed on section 2.4. The approach delivered a Navisworks® model with links to the facility documentation, like drawings, O&M manuals, warranties, and specifications among others. The model was available for the staff in charge of the operation and maintenance, they were trained in navigating the 3D model and retrieve information from the objects in the model. The interview focused on the experience during the first year of implementation of this approach.

One of the main concerns expressed by Baker was that the model is barely used for information retrieval, because of two main reasons, the lack of time because of the daily workload and the technical challenge implied in handling and navigating through a 3D model, is a tool that is new for most of the staff and the natural issues of shifting to a new technology were the main factor for not exploiting the full potential of this approach.

On the other hand the model is live linked to a SharePoint repository where all the digital documentation resides. The process of linking the components of the model to the files with the information on warranties, O&M manuals, specification, drawings, etc. produced a repository of well sorted and organized documentation into the SharePoint repository, which by itself represent an important improvement in relation to the previous approaches of handing over this information. The repository is used without the model with improvement in the performance of finding and retrieving information.

Another advantage of the approach is the model fed the information needed for space management, which is the commodity with highest priority for the institution, it was accurate and reliable, the space management staff uses Archibus® and the information were gathered from the model.

In the process of importing the information into the CMMS they used COBie and the process of creating the spreadsheet was an overwhelming challenge. The COBie files were created at the end of the construction and they fell it would be better if they filled as the same time the information is available through the design and construction stages.

During this year the building have suffered small changes such as replacing a pump and re-balancing electrical circuits, those changes have not been updated in the model; there is not a formal policy stablished for that purpose.

There is no other new facility to be built in the near future but Baker expressed the willing to use this approach again with enhances in the issues they found in this first project, the expectancy is the challenge of handling a 3D model can be overcome in the future as the technology become familiar to the staff. They will put emphasis in preparing the model and the information as they are generated through the design and construction stages,

BIM offered several benefits during design and construction, particularly for design approval from the users, because of the communication power of a 3D model. BIM also have proved benefits for the 3D coordination of the different trades involved in the facility. Therefore, as the use of BIM is becoming part the standard approach for design and construction the extra effort to deliver the model and information to the facilities staff is feasible and desired.

For existing facilities, there is no expectancy of creating the models even when the benefit for the use of the models for space management is evident, the current approach using Archibus® is enough for now. The return of investment (ROI) on creating the models for MEP operation and maintenance is not favorable, mainly because the actual model is barely used, when this issue can be addressed the ROI should be favorable. An isolated case were a 3D model were created occurred on the power plant addition, because of the 3D coordination with the MEP of the addition. Normally the renovations uses 2D drawings, 3D models are only used for the purpose of project presentation to the users.

5.4.2 Survey

As part of the applicability validation an online survey was conducted targeting top level facility management staff. The distribution list was of 121 staff from colleges. 14 people respond the survey.

The survey asked about the handover process, the information management for the FM and the use of BIM, the survey is included in the appendix E. The results of the survey are discuses in this section.

The demographic characteristics of the participants showed an even distribution on the type of academic programs offered, very similar to campus used in the case study. See figure 22.

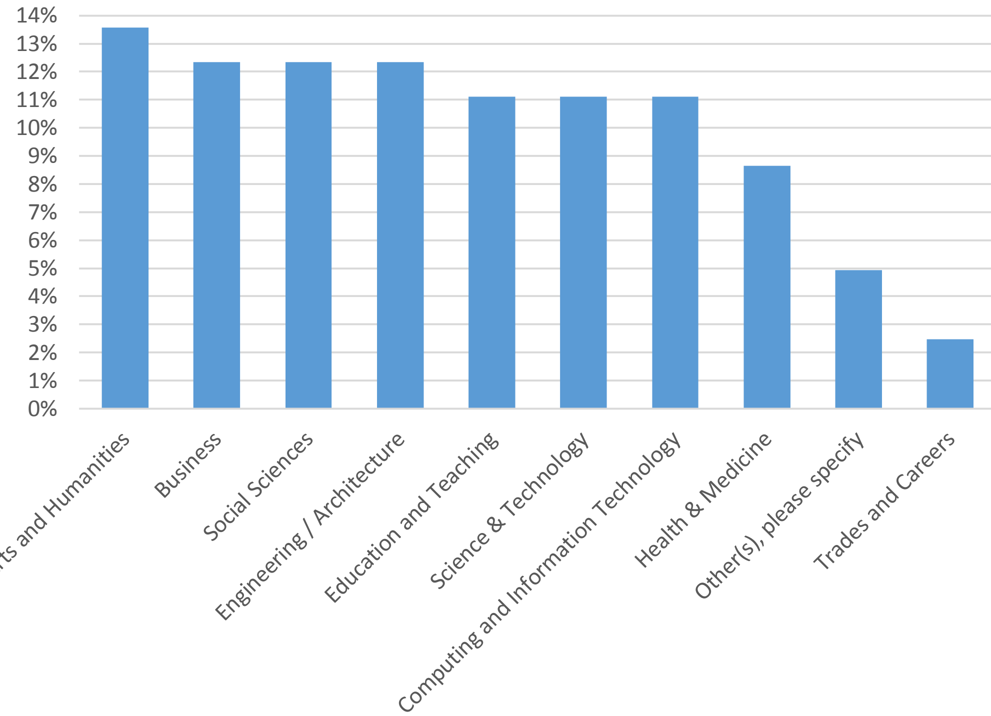

Figure 22 Main programs offered at surveyed colleges

The size of the colleges, showed that the sample have representation of the three categories. See figure 23.

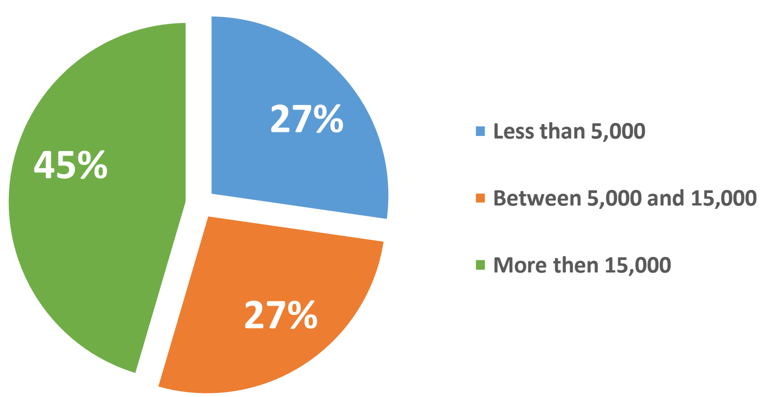

Figure 23 Size of the surveyed colleges

An important proportion of participants expressed the use of BIM at certain degree on some of the stages of the lifecycle of their facilities. From the sector who uses BIM expressed the main use for the design development and construction stage, a small proportion declared the use of BIM for the operation and maintenance. See figure 24 below.

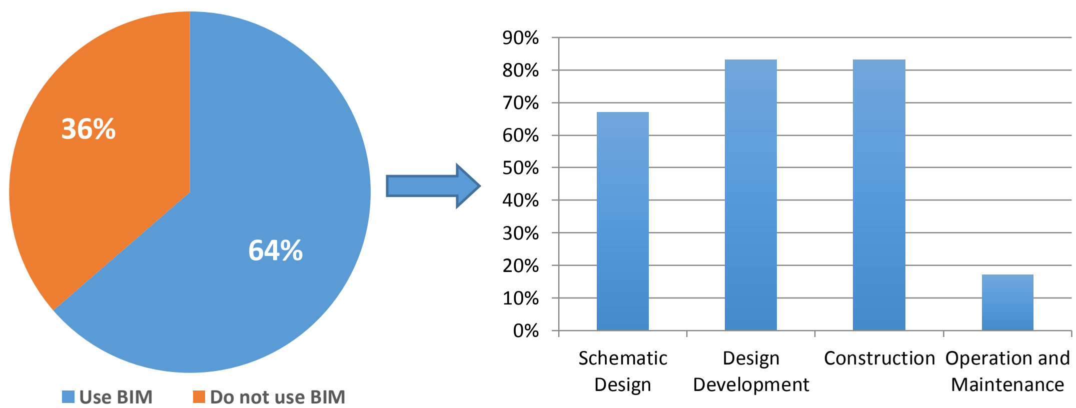

Figure 24 Proportion of colleges using BIM

The most used method for delivery information from the contractor to the FM staff is via digital media as a set of scanned documents, excel files and CAD files as is shown in the figure 25 below. In this figure the percentage number in the sectors represents the average proportion of the number of projects that uses the corresponding delivery method for the BIM and No-BIM groups.

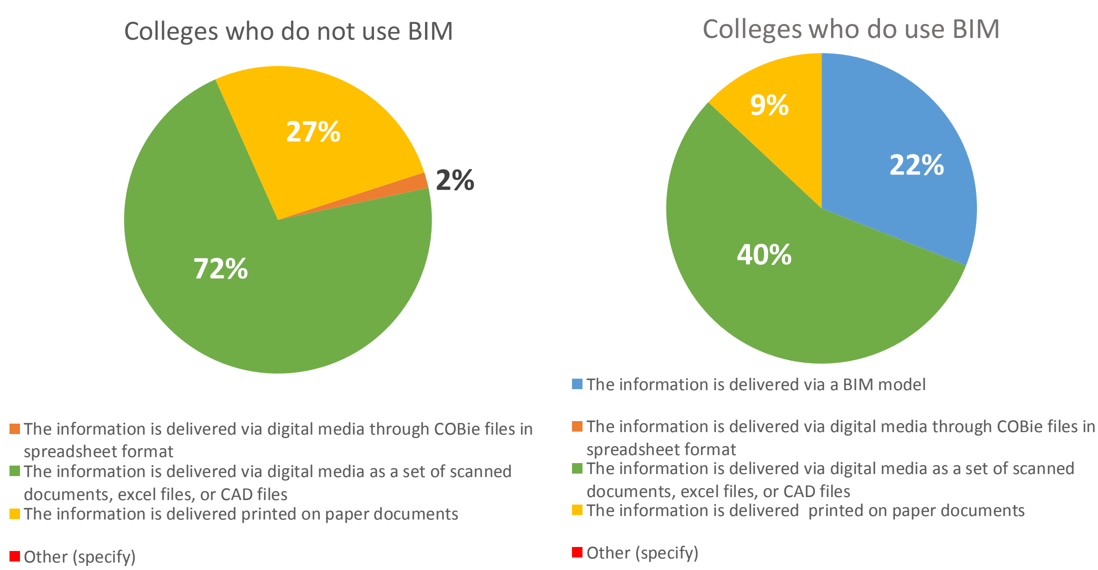

Figure 25 Information delivery methods used

FM department from colleges who are using BIM expressed that in 22 percent of their projects the information is delivered with the support of BIM.

From the colleges who are not using BIM expressed that only in a small percentage (2% in average) of their projects uses COBie as the method for handover the information.

When asked about the convenience of the handover method for different purposes during the operation and maintenance of the facility, the colleges who are not using BIM expressed and overall lower satisfaction in the usability of the information handed over the colleges who are using BIM. See figures 26 and 27.

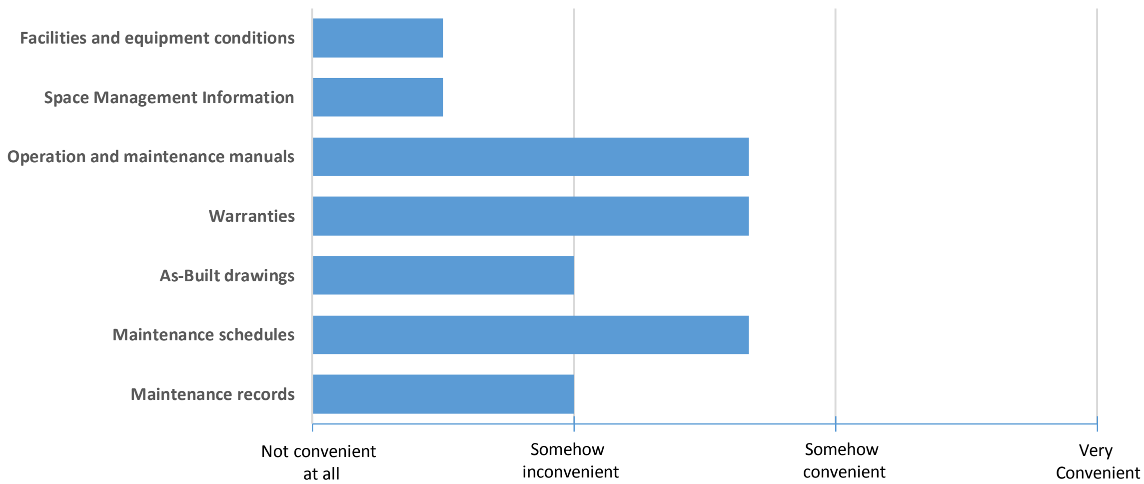

Figure 26 Convenience of the information delivery methods for the use of different type of information at the operation and maintenance stage for the schools who are not using BIM

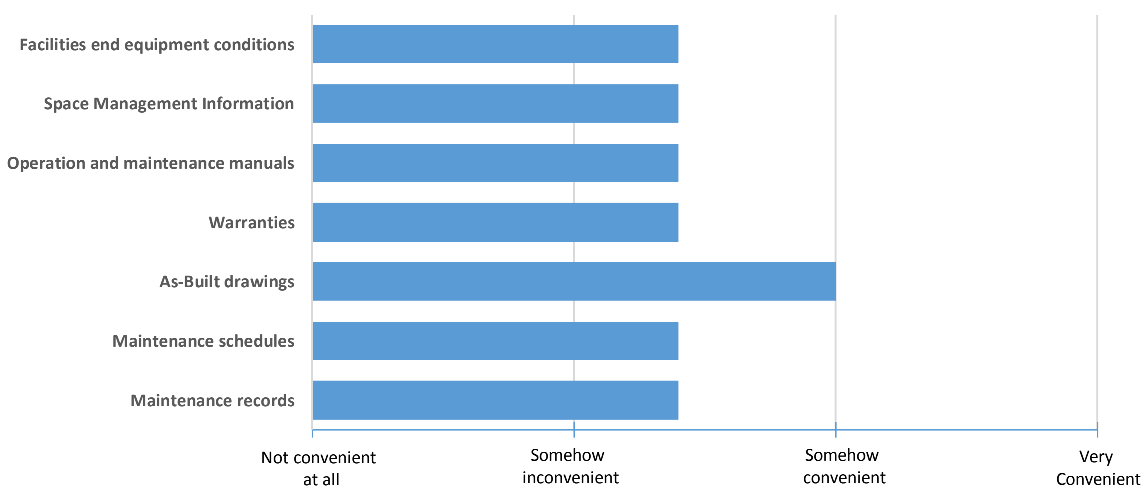

Figure 27 Convenience of the information delivery methods for the use of different type of information at the operation and maintenance stage for the schools who are using BIM

Is remarkable the contrast on the uniformity between the colleges who are using BIM and those who are not, on the satisfaction level of the usability of the information for the operation and maintenance of a facility, BIM trend to standardize processes, and even when the level of convenience has a room for improvements, it is more consistent among the different processes. Another aspect to remark is the higher convenience on the “As-built drawings” when BIM is used in the process.

The next topic of the survey was about the methods used for managing the information handed over, among the colleges who do not use BIM the most used method is relying on printed or scanned documents with exception of the maintenance records and schedules in which the use of a CAFM or CMMS are the main method (see figure 28 below). Among the colleges who uses BIM there those are also the main methods but in a more balanced fashion, with the exception of warranties and O&M manual where printed or scanned documents is clearly the predominant method. There is a small percentage of colleges who are starting to use BIM for maintenance record, As-Built drawings and space management. This can be observed on figure 29.

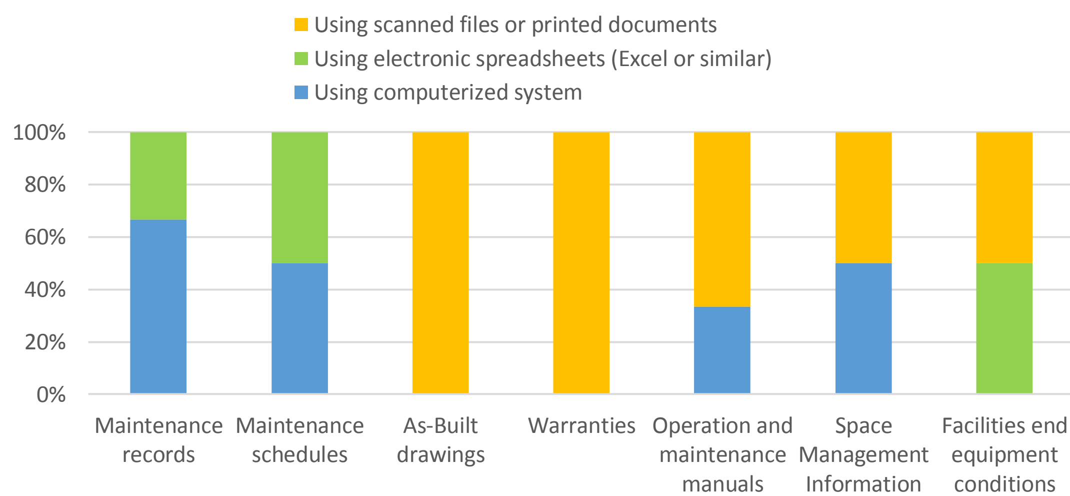

Figure 28 Information management methods for different documentation at the operation and maintenance stage for the schools who are not using BIM

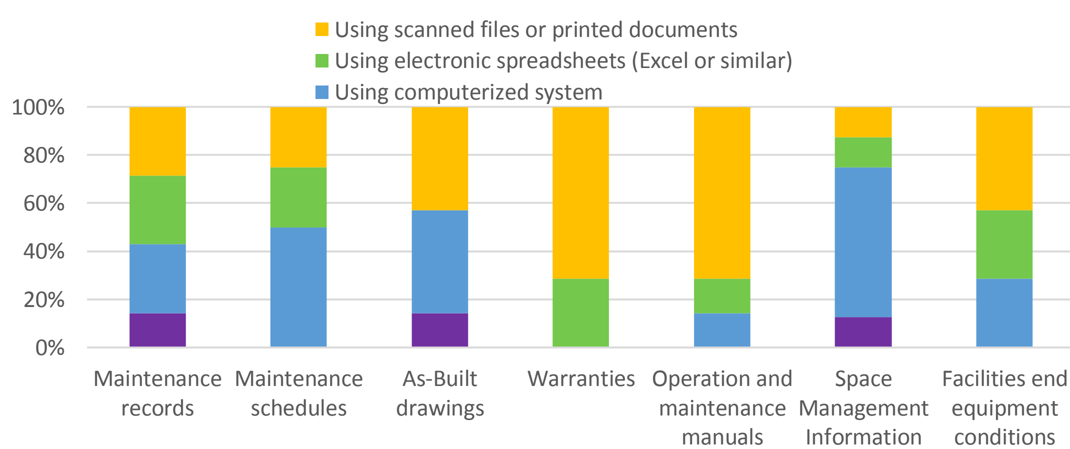

Figure 29 Information management methods for different documentation at the operation and maintenance stage for the schools who are using BIM

Figure 30 below shows the most recurred practice to locate information on an equipment it locating the model, brand, or ID directly on the equipment, and then locate the document in the filing system. In the case of the colleges who do not use BIM this is the method reported by all the participants in the survey, while in the colleges who are using BIM this account for the 75% and the remaining 25% rely on the CMMS that contain all the information to identify the equipment then locate the document in the filing system. Having to identify the equipment physically is the most time consuming method because it is a common scenario that getting physical access to the equipment is a challenging task.

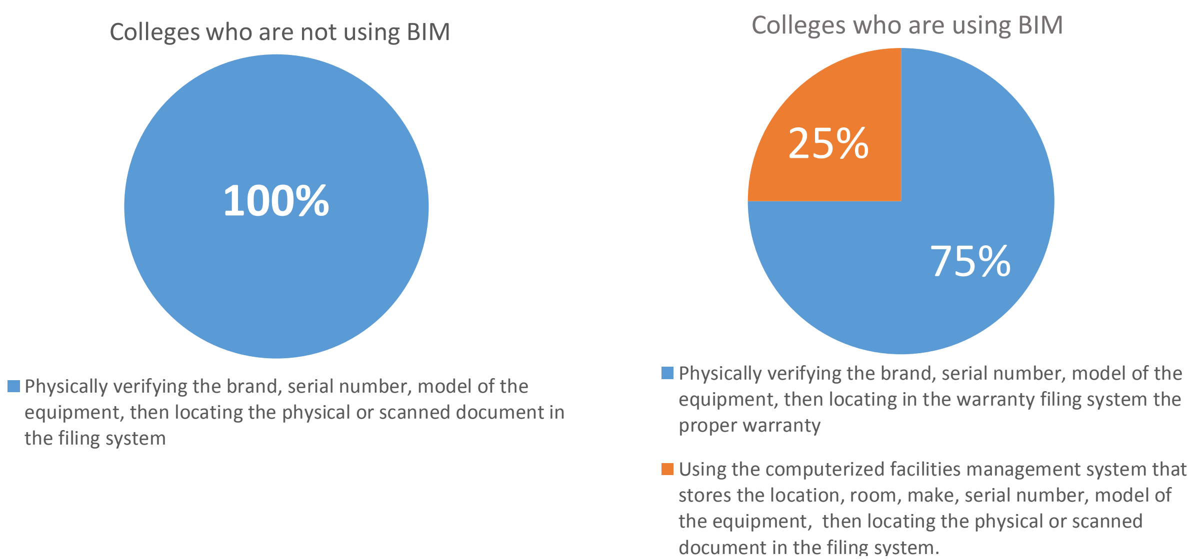

Figure 30 Method for retrieval warranty documentation for equipment

5.4.3 Interview and survey conclusion

The interview and the survey support the premises of the current approach which are:

- The handover process is paper based which is the less efficient method as the information of this method lacks of structure resulting in low reusability and the need of retyping the information as is needed, practice that is prone to errors.
- This method of handing over the information is perceived by the FM staff as not the most convenient for the future use of the information.
- There is an important proportion of colleges who are already using BIM at some degree in different stages of the lifecycle of the projects.
- The use of BIM for the handover and during the operation and maintenance stage is still in the very early adoption.
- Successful implementation of BIM for the handover such as the case of the University of Massachusetts, even when some flaws on the using of the models during the O&M stage. The lessons learned on this flaws for future improvement, and the efforts to sort, filter, structure, and deliver the information using BIM has proven be worthy.

6 BIM-Enabled Digital Handover process

This chapter proposes a BIM-Enabled Digital Handover process that is formulated on the basis of research and findings documented primarily in chapters 2, 4 and 5 of this report. This material is organized and presented in two parts. First the part (sections 6.1 and 6.2) discusses the importance of the Information Delivery Manual and describes the proposed Model View Definition. The second part discusses the technical validation (section 6.3).

6.1 Strategic process approach

One of the major issues from the facility manager point of view is that the amount of information that is included in the BIM model during design and construction surpasses the amount of information that is needed or that not all of the information that is needed for facilities management is included in the model. When either or both of these situations arise the facility manager needs to go through the overwhelming task of filtering out the information that is not needed, or go through the additional task of collecting and adding information beyond what was needed for the design and construction however it is needed for the rest of the life cycle of the facility.

Using BIM efficiently to support the FM process implies the consideration of both of the above identified situations during the creation and updating of the model during the planning, programming, design, construction and commissioning stages, therefore such stages take place in such a way that the “as-built” version of the BIM model is ready at the time of the handover process. Three main possible scenarios were considered in the strategic approach to develop the process for a BIM-Enabled Digital Handover:

- Scenario A: Deliver the model as a part of the handover to the owner and transferring the responsibility to the FM staff for extracting the information needed for populating their CAFM systems.
- Scenario B: Extract the information from the model into a file that is readable by the current CAFM system of the owner and deliver such files in the handover.
- Scenario C: Extract selected information from the model into a file that is readable by the current CAFM system of the owner; include the file and a BIM version that can be used by the FM staff to support its processes.

In the scenario “A” the responsibility for extracting the information relies on the FM staff. Relying on the completeness, integrity of the information contained in the BIM and seamless transfer it to the CAFM implies a high risk. For this scenario to succeed the verification of the completeness, integrity and format of the information included in the BIM needs to be assured. In addition the BIM currently does not include all the information the FM staff needs. There is not reliable software solution that guarantees a successful transference of the information from a BIM to a CAFM. It is possible to query the BIM by using third party tools and then copy this information into the CAFM but this process is likely to be equally or more time-consuming process than re-typing the information from a printed paper document.

Scenario “B” transfers the responsibility for extracting the information to the main contractor or a consultant. Under this scenario a file is created containing the extracted information from the BIM that is needed by the FM staff. The information that cannot be included in the BIM is added separately to the file. The file is delivered as part of the handover process and later used for the FM staff to populate their CAFM system. This scenario is one of the most commonly followed by owners using BIM such as the General Services Administration (GSA) and many universities who are using this approach. This file is usually in compliance of the COBie format. Under this scenario, the file needs to be verified in order to guarantee that the completeness, integrity and format of the information meet the owner requirements and that the owner's CAFM system is to be capable of reading that file.

The scenario "C" is something in the middle, Scenario "A" focuses on a version of the model that contains all of the information needed by the FM staff but it requires additional verification work. Scenario "B" focuses on producing an intermediate file for transferring the information from the BIM to the owner's CAFM. Scenario "C" enables BIM to report information to a file for populating the owner's CAFM system and at the same time delivers a BIM that can be used to support the FM process. For this scenario to succeed, a verification on the capability of the model to produce an intermediate file with the information needed to populate the CAFM, such as a COBIE file, an IFC file or a structured data file, that can be used to populate the CAFM. The BIM also need to be prepared to support the FM process in areas where the BIM characteristics provide greater value than the traditional CAFM. Table 1 below summarizes the three scenarios

Table 5 Scenario Comparison

	Scenario A	Scenario B	Scenario C
What is delivered?	A BIM with the information for FM integrated into the model	A file readable by the CAFM with the information for FM integrated. The BIM delivery is optional	A BIM with the information for the FM integrated into the model capable of produce a file readable by the CAFM.
Risk Involved	High, due the current unavailability of a software solution for transferring the information from the BIM to the CAFM	Moderated, the file needs to be verified and supported by the CAFM.	Moderated: The model and the file needs to be verified.
Usability of the BIM for supporting the FM process	Moderated as the effort is to focus in integrate the information not in the usability of the BIM for FM	Low, as the file is the requirement, the model is the one that was used for previous stages not prepared for the use on FM.	High, due the balance on the capabilities of the model to populate the CAFM and support the FM process
Effort needed for creating a BIM version for FM	High, focused on the integration of the information.	Low as the main deliverable is the file with the FM information	High because is a version for FM with the LOD for that purpose
Supplemental Information (warranties O&M manuals, etc.)	Linked to the model	Linked to the file	Linked to the model

BIM will never replace the functionality of current FM systems. Under any of the three defined scenarios the model will carry information that is needed to support the FM process and some intermediate process is still needed to extract some information from the model in order to populate the CAFM. Current approaches fall under some of these scenarios but still in early development with many issues (see section 5.3), this practices are not yet mature enough to be considered fully reliable. Producing readable files in open standard formats like the COBie requires a lot of effort and are not supported by many CAFMs; proprietary standards based on commercial BIM authoring tools, are frequently updated offering no backward compatibility with previous versions.

It is essentially important to have a clear idea of what information is needed in the intermediate files as well as what is the appropriate format to use; this mainly depends on the system where the information will be used, the policies and, the configuration the organization set up in the use of such system. FM managements systems are flexible, and even when two organizations use the same brand of system, the way in which each organization uses the system can be quite different and by consequence the information that is needed. This means that an intermediate file for transferring the information from the model to the CAFM also needs to be flexible.

Working with intermediate files that contain information extracted from the model and to be used for populating the FM system do not usually have the capability for allowing the delivery of supplemental information that is linked to some elements of the building. This information is usually handled separately and delivered that way. This type of supplemental information includes warranties and operation and maintenance manuals. Therefore these documents need to be linked again in the FM system or managed manually.

In addition of transferring information from the BIM model to the CAFM model, the delivery of the BIM model itself which is prepared for the use of the facilities management staff offers some advantages, such as the power of visualization and location awareness, usually not possible in most of the FM systems. This model can preserve the links to attached files (digital copies of warranties and O&M manual among others) and make these documents available for retrieval during the FM process as needed. On the other hand, the delivery of a FM-usable model presents challenges such as the selection of a format and user interface that is convenient for the use of FM staff. At this point in time there is no a specific software solution for such purpose, however some clever approaches in which adapting software used for other purposes have been used with success. This creates a new market niche to be exploited by software vendors.

Regardless of what approach is used, one factor that affects the success of using BIM for delivering information during the handover process, deals essentially with the way the model is created. This is a recognized factor in all aspects of BIM modeling. Knowing ahead of time what will be the purpose for the information, determines the proper way the model is to be created. When the final use of the model will support the FM process, it demands a modeling approach that serves such purpose. The model needs to be created to respond to a determinate work flow, disciplines and organization. Instead, the creation of the model is frequently driven by the BIM modeler's knowledge of the authoring tool who rather focuses in the easiest and fastest way to create the model. The same way a big concrete floor slab that is being modeled for construction purposes shows its sections as they will be poured on site, as opposed as the same concrete floor slab being modeled as a complete unit that supports functional space of human activity. For FM purposes the same concrete floor slab can be modeled for cleaning scheduling in sections representing different types of floor finishes. A construction project involves several parties: designers, contractor, subcontractor, among others, therefore, creating a single model that satisfies many purposes is very unlikely. The common approach is to integrate the information from the different parties in a 3D coordination software, however, each model may have different structure and organization, enough for 3D coordination but not necessarily adequate for integrating and delivering information for FM purposes as well

The proposed approach of this research is based in the following premises which summarize the findings of the literature review and the case study:

- It should be based on open standards to facilitate interoperability and provide longevity of the approach and the implementation
- It should be fully structured; therefore the information in the approach can be reusable.
- It should clearly define specifications for the implementation at the schematic design, design development, construction and operation and maintenance stages.
- It should be capable of delivery the FM information for supporting the "Operation and Maintenance" and "Space Management" processes
- It should be capable of deliver a workable model for the use of FM staff
- It should be applicable to existing facilities

6.2 Information Delivery Manual (IDM) and Model View Definition (MVD)

BIM is a technology that offers several benefits to its users (Eastman 2012). Creating a model properly requires understanding and proficiency in the use of the BIM authoring tool as well as knowledge of the professional discipline and the contextual setting in which the models are used. The more uses the model has along the project lifecycle, the more complex the model becomes, therefore at the end of the construction the model needs to be cleaned up and prepared for its use during the longest stage of the project lifecycle, that is the operation and maintenance of the facility, otherwise, the amount of information that is built in the BIM model during design and construction surpasses the amount of information that is needed or not all of the information that is needed for facilities management is included in the model.

In preparing a model for a specific use, the following characteristics of the information contained in the model need to be present:

- Organization
- Consistency
- Integrity

Organization will allow the user to quickly find the information they need. An organization structure guides the user through the model for creating, storing or retrieving the information and its related components. Such organization is preferable to be in compliance with an open standard rather than a adopting a proprietary organization structure. This will facilitate implementation and support from the future generations of software tools.

Consistency will guarantee that the information is systematically created and handled in the proper format; including, units, naming and numbering conventions used by the Facilities department or its Computerized Management System.

Integrity will guarantee that all the components needed in the model has complete and reliable information attached to them.

These characteristics in conjunction with the specified criteria on what needs to be included in the model for the use during the maintenance and operation stage are usually stated in two documents: the Information Delivery Manual (IDM), which is intended for the users and the Model View Definition (MVD) which is the guideline for the creators of the model.

The IDM supports the business process, the business requirement and the software solution. Supporting the business process, means to understand the business objectives of the organization as well as the workflow that is followed in the facilities management process. This is usually documented with the use of process maps in which the information exchanges are identified.

Supporting the business requirements means that once the information exchange requirements are identified are clearly defined in non-technical terms known as “functional parts” in the IDM. This definition is used by designers, contractors and facilities managers to identify the type of information and at what stage the information should be created. The exchange requirements are also utilized by the software solution provider. This a key technical detail that enables the solution to be efficiently implemented. Supporting the software solution and its implementation requires definition of functional parts under one information structure called “schema”, usually following an open standard. The functional part is a consistent and reusable set of units of information or “concepts”.

The components of the IDM and MVD are the means for deploying the implementation of the BIM in the workflow by the users, the software solution based on the selected BIM authoring software used to create the model, and the information model which is the BIM with the information needed to support the facilities management process.

The link between the deployment and the software solution is the exchange requirement. The link between the information model and software solution is the model view definition. Figure 31 displays these components. The deployment and exchange requirement are the main components of the IDM, the software solution and the model view definitions are the main components of the MVD, the information model is the systematic aggregation of all these components

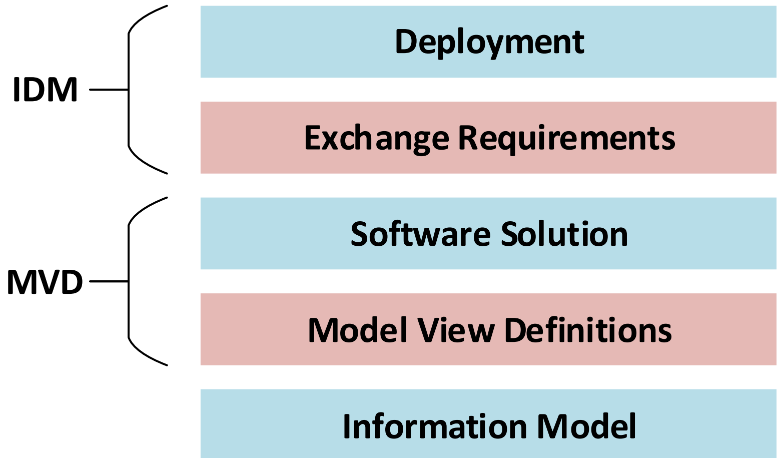

Figure 31 Components of the IDM and MVD (Building Smart Alliance, 2007)

The IDM technical expression is defined by the Functional Parts, while for the MVD this is accomplished through the Concepts, as shown on Figure 32. A Functional Part is a unit of information or a single information idea; it is used by the solution provider to support the exchange requirement. It describes the information in terms of the required capabilities of the information model. A Concept is a component that is adopted by the by the IDM from the model view definition approach. In this case the IFC schema.

Functional Parts and Concepts are equivalents each in its own domain. Functional Parts express a larger set of information whereas Concepts are more specific sets of information that are mapped to one or many Functional Parts. Concepts in these contexts can be reusable.

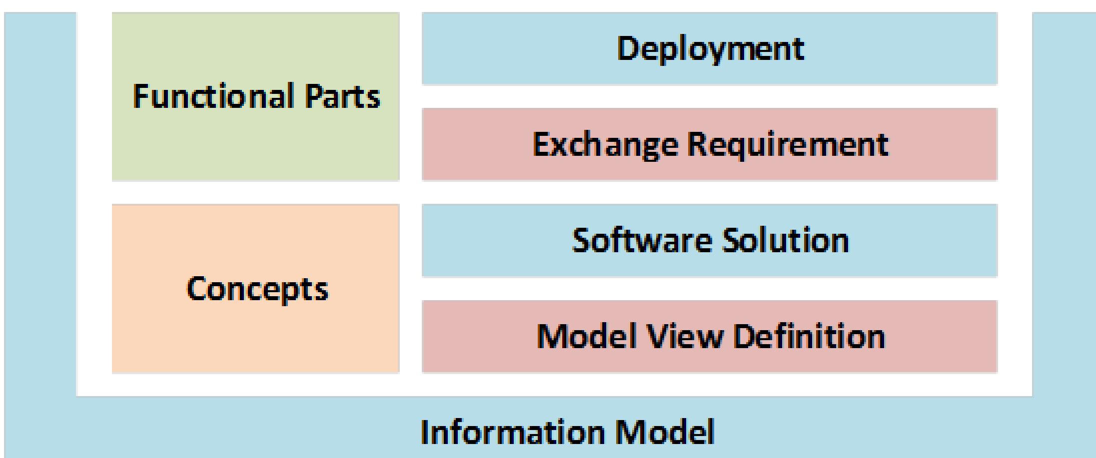

Figure 32 Functional Parts and Concepts as technical expressions of the IDM and MVD (Building Smart Alliance 2007)

A process map describes the flow of activities within the boundaries of the facilities management processes. Its purpose is to understand the task, actors and information requirements, consumed and produced. It captures multiple business requirements that are supported by exchange requirements. A process map for the deployment of the BIM in the workflow of the facilities management process should have support from only one model view definition; however a model view definition can support multiple process maps (see Figure 33)

An exchange requirement is a set of information that support some activities of the process at a particular stage. An exchange requirement is intended to provide a description of the information in non-technical terms; this is for the use of the designer, contractor of facility manager. It is supported by one or more functional parts.

A view definition is the schema of the information model that will be used, for this research the implementation of the IFC schema is proposed. It captures multiple concepts. A functional part may be developed using one or more concepts. A concept may be implemented through one or more concept bindings which is the implementation of the concept and is related to a specific release of the model view definition schema. A concept is implemented through a concept binding. Each binding is related to a single element of the standard schema.

An exchange requirement may capture one or more business propositions which describe the operations definitions and constrains that may be applied to a set of data used for the support of a particular task or process in non-technical terms. A business proposition is implemented as exactly one business rule. This can be more clearly understood in the figure 33.

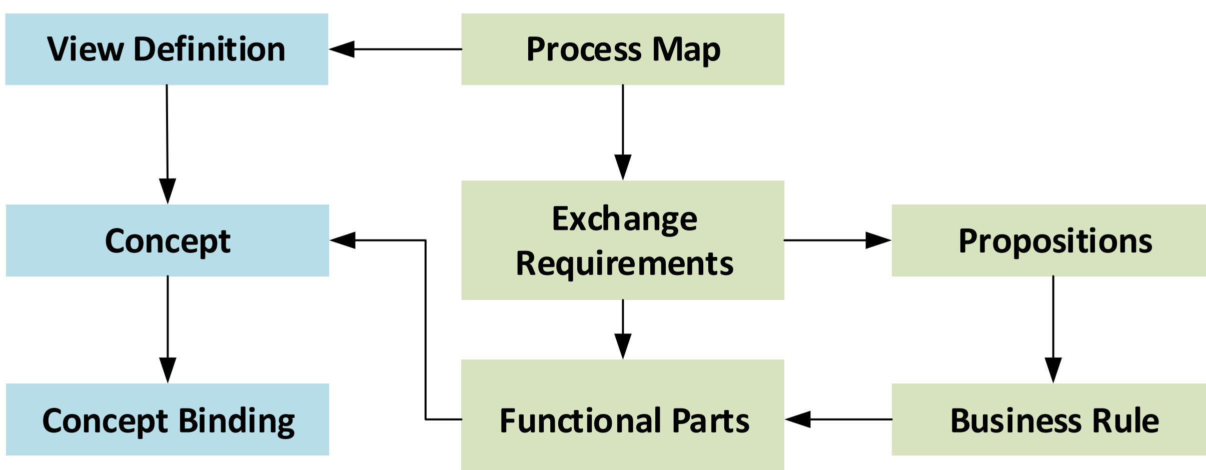

Figure 33 IDM/MVD cross relationship schema (building Smart Alliance, 2007)

Business Rules describe the operations definitions and constrains that may be applied to a set of data used for the support of a particular task or process. Business Rules have the following characteristics:

- *Use of specific entities.*
- *Attributes and properties that must be asserted*
- *Values, or range of vales,*
- *Dependency between entities attributes or values.*

Business Rules are expressed in terms of the logical form in accordance with the attribute/property of the functional part to which is applied.

The IDM has three target actors:

- **The executive user**

  The executive user is the person who is aware of the business process as well as the impact of improvements in the execution will have at the organization level. The Executive user does not have technical detail on the use of the information and is not proficient in the use of BIM software tools, or model view definition schemes.

- **The end user**

  The end user is the person who uses the BIM for information exchange, needs to know exactly what information to expect and how to use it in the process. However does not know how to create BIM models or any other software development. It proficiency is only in the use and handling the model for information retrieval, use and updating.

- **The solution provider**

  A solution provider is a person or organization that writes a software application with a BIM interface, knows exactly what information to expect and how to use it in the process, need to know how to handle and create a BIM model and the model view definition adopted.

For this research the executive user are the top managers of the facilities management departments, the end user are the designers, contractors and facilities management staff who will provide or use the information into and from the model. The solution provider are the BIM proficient staff in the designer, contractor and facilities management teams who are in charge of creating the model and prepare it to receive the information (instances and attributes) needed in the model, in compliance with the model view definition selected.

The approach herein proposed is initially described by two process maps for the main functions of the FM department, which are Space Management and Operation and Maintenance. The maps are discussed in section 6.2.1; those identify the information exchange requirements which are discussed in section 6.2.3. Lastly, the model view definition proposed to support the information exchange requirement, the functional parts and the concepts are widely discussed in section 6.2.4

6.2.1 What is a model view definition?

Is very important to understand what a model view definition is and why it is needed, this section discuss this topic.

The Industry Foundation Classes or IFC, are a well mature standard which is maintained by the Building Smart International Alliance as it was explained in section 2.5. It is a response of the need to exchange BIM information through models between different software packages. The IFC is a robust standard which require a high level or expertize for understanding it.

In the efforts of being a comprehensive solution that can handle all of the different uses of the model implemented by different software packages made the definition of the IFC really intimidating, as an example see the partial diagram of a wall definition of the IFC 4.0 in the figure 34 below.

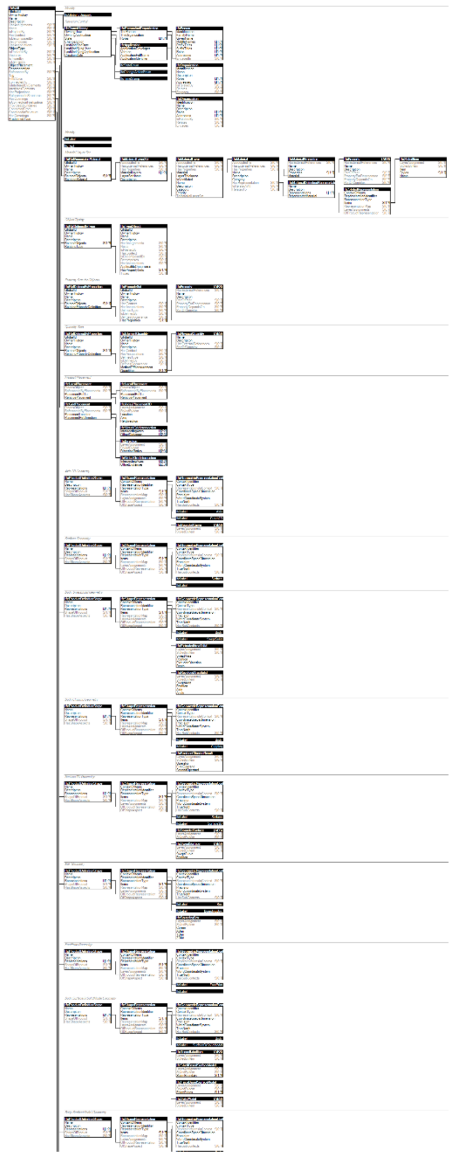

Figure 34 Section of the diagram of the definition of the wall functional part of the IFC standard

Exporting a wall of a model into the IFC format does not mean that the whole definition of the wall needs to be fulfilled, is very unlikely that a BIM authoring software has all the information to be fully compliance of the IFC definition, the information that the model have depends on the use of it. This is where the model view definition is useful, the model view definition identify depending on the use of the model, what parts, of the wall definition (following with the same example) needs to be exported an where to put that information (See figure 35). This is the way a BIM authoring software knows what information to export, following the specification of the model view definition for a particular purpose.

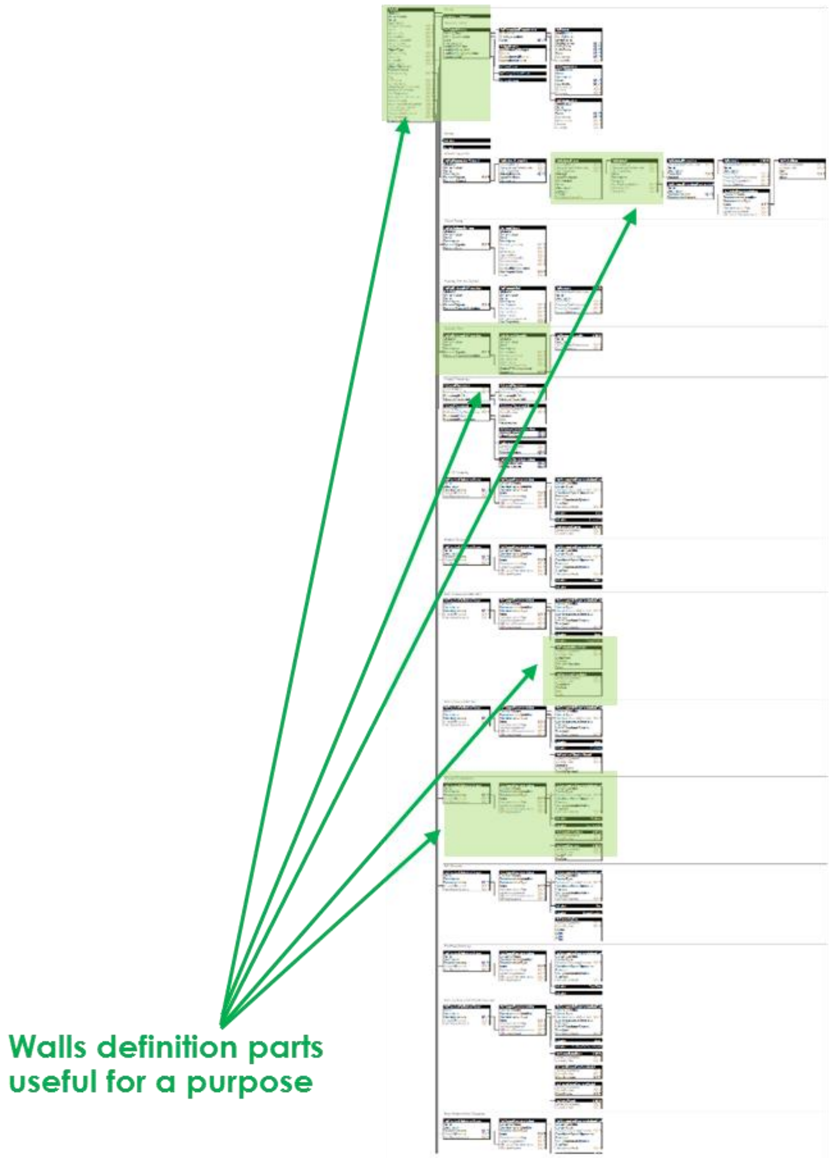

Figure 35 Schematic example of a model view definition for a determinate use

The most widely known model view definition of the IFC is the 3D coordination model view definition, which is used for combining different models from different trades, and detecting and solving physical interferences between the trades. This model view definition is focused on the geometric characteristics of the elements which is the fundamental information of the 3D coordination. This model view definition is the basis for other model view definitions as it contains the basic information of the elements of the model.

The IFC has a model view definition named FM-Basic model view definition, as the name implies its purpose is to deliver information for the FM process. Is the model view definition that is used by the COBie approach and the one selected by this research as the starting point.

In this research it is proposed the extension of the FM-Basic model view definition according to the findings on the literature review and case study.

6.2.2 Business process

There are two major processes in a typical facilities department of a college organization; the space management process and the maintenance and operation process. Both include several sub processes and tasks and are graphically displayed in detail in Appendix B. However the main components of the process maps are discussed in this section. The information exchange requirements herein identified and defined support of all of the sub-processes and its corresponding tasks.

In mapping these two processes, it is assumed that the designer, the contractor and the owner (through the facilities management department) are committed to the implementation of BIM throughout the project lifecycle. The activities and relationships performed by each of these participants are clearly identified in the process map as well how these relate to the information model

6.2.2.1 Space management process

The main purpose of any facility is to provide the appropriate functional space to support the activities that will take place in the facility. Spaces are usually expressed in terms of rentable area for commercial use. For schools and universities the Post-secondary Education Facilities Inventory and Classification Manual (NCES, 2006) classify the space in three types of areas.

- **Gross Area**, which is the footprint of the facility,
- **Net Usable Area**, defined as de area of the usable space without taking into account the area occupied by the structure
- **Net Assignable Area**, defined as the Net Usable Area deducting the building service area, the circulation area and the mechanical area.

For this case the choice is net usable area as the main attribute of the space. Gross area can be obtained in a BIM without the need to specifically attribute it to a zone. Net assignable area can be differentiated by grouping the spaces uses.

Spaces are one of the first elements that are defined by the designer, this is part of the requirements obtained from the owner and explicitly declared in the program (Hershberger, 2000). It includes a list of the spaces by function and by size. The program is defined in the early stages of the project, during the planning stage, however, it is in typically at the schematic design when the first version of the model can be delivered (see figure 36 below). It is in this version of the model that the information regarding the spaces is incorporated (see section 6.2.3 for details on the information).

The schematic design model may be the basis for the development of the next stage model corresponding to the design development During this stage the design is completed with all the level of detail pertaining to the elements, systems and technical specifications as needed by the construction team. Therefore all the coverings and treatments of the elements forming the boundary of the space are defined and its corresponding information needs to be attached to the space entities. This may be automatically attached to the space depending on the BIM authoring tool that is being used. However this always needs to be verified.

6.2.2.2 Operation and maintenance process

The efficient utilization of a constructed facility relies on the proper maintenance of the systems of the facility. This type of work as is the most resource demanding process in a facilities management department. It requires anticipation and preparation for the gradual deterioration and even failure of the systems to avoid disruptions and delays during the operation of the facility.

The operation and maintenance process relies on timely and accurate information to keep the facility systems up and running. This information supports diverse decisions related to situations such as to how to start up and shut down a system, what maintenance tasks and when those need to be performed on the systems, what safety procedures and hot to access the system components to be maintained, when it is better to replace and equipment that keep maintaining it, when something fails who to call to for warranty claiming and how to respond on emergency. These are some of the common scenarios the facilities management staff deals in their daily workflow.

In a similar fashion as the on the case for the space management process, Information about the location of the systems to maintain is crucial for maintenance planning or to respond to emergencies. Therefore, the information begins to be identified and defined at early stages at the schematic design stage, when the type and location of these spaces are defined. Different from the case of space management, however, the location of the space by itself is not so important for the case of maintenance. This importance begins to be significant for maintenance at the stage in which systems begin to be defined and hosted in the facility spaces. This happens during the design development stage. The parametric and object orientation characteristics of BIM authoring tools allow establishing a clear relation between a given system and the elements that are part of that system. The location of the element is automatically identified by most BIM authoring software, however, if this is not the case, the location of the element needs to be entered explicitly by the modeler or designer. In any event, the location of the element is key for future operation and maintenance procedures and needs to be verified even when the software handles It. Size, dimensions, materials are examples of other attributes that are also defined in this stage (see section 6.2.2 for details on the information).

During the construction stage the different systems, materials and other components of the facility are installed and tested. Each of these elements have information related to them such as brand name, model type, serial number, spare parts, warranty, operation and maintenance manuals, inspection, and startup reports among others. This information is key for the day to day tasks of the facilities staff who is in charge of operating and maintaining the facility. This information needs to be attached to the systems and its components in accordance with the proposed information exchange definition (see section 6.2.3).

6.2.2.3 Workflow common for the Space Management process and for the Operation and Maintenance process

There are some workflow that is common for both of the processes included in this proposal starting at the end of the design development stage, were a complete BIM model with most of the elements at a level of development (LOD) of 350 (AIA 2013) is obtained. This model is of particular importance because depending on the project delivery system and type of contract used, this will be the link, from the modeling point of view, between the designer and the contractor. This is a natural milestone in the model development and the appropriate quality assurance and quality control may be applied to guarantee that the model meets the information exchange requirements and it will be in compliance with the model view definition selected. In the proposed approach, the model will be set in such a way that it will meet with the specified FM-Basic Handover schema (Building Smart International, 2010b)

In the approach herein proposed it is assumed that some sort of contractual agreement in the project that requires sharing of the model carried out up to design development stage with the contractor, whom in turn may use it for its own purposes as well as continuing developing the model in preparation for the future handover at the end of the construction stage.

Specified materials and geometry for the facility are followed as prescribed by the design. Any changes taking place during construction need to be updated in the model

One important part of the model documentation process relates to the way the information is attached to the elements of the BIM. By default the BIM components of the BIM authoring software does not have predefined attribute holders for this information. Therefore the designer, the contractor and the facility manager need to clearly specify and implement them in the model as part of the BIM Project Execution Plan. The specific technical implementation of this procedure may vary with each BIM authoring software, but, for the most part, today's commercial BIM authoring software has a way to define these attribute holders for attaching information to the BIM components. In the same way, most of the commercial software today is capable of translating this information to an exchange file in compliance with the IFC Basic Handover model view definition, which is the one proposed in this research (see section 6.2.3). Constant verification and updating of these attributes need to be done by the designer/contractor (depending on the agreement) during design and construction.

Usually the as-built drawings are a part of the contractual requirements in most projects. The proposed approach assumes that in additional to this requirement, or in lieu of it, the as-built model is also required. During the construction stage the specified systems, materials and geometry for the facility are followed as prescribed by the design. Any changes taking place during construction need to be updated in the model of the facility and are reflected in the as-built model.

At the end of the construction another important milestone is reached, this is when the handover takes place and the model is delivered to the owner. Herein it is proposed that two versions of this model be handed over.

The first one that is submitted is the model that has been gradually developed through all previous project development stages. The model contains all information that was necessary for the design and construction of the facility and is also in compliance with the BIM guidelines for the owner. Usually this model is in a software proprietary format, depending on what brand of software the owner needs it. This model could be used in future renovations. Therefore it has the level of development implemented by the contractor or required by the owner which may be 350, 400 or 500, and a high level of detail, see figure 34 below.

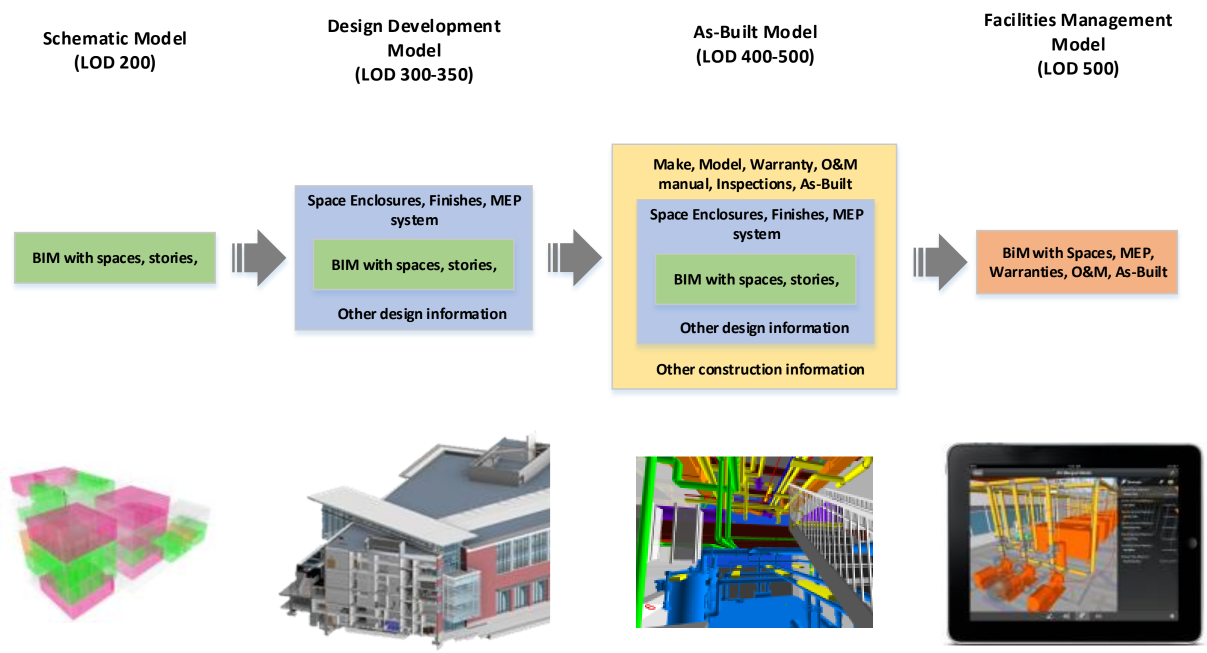

Figure 36 Evolution of the model

The second version of the model is a "light" version of the first model, which does not need to contain much of the information needed during design and construction. Therefore, the first model needs to be "filtered out" to contain exclusively the information that is of value for facilities management. The creation of the second model effectively eliminates the "Tsunami" effect previously described in Chapter 2. It requires providing accuracy in the dimensions and in the location of the components. The production of this second "light" model does not demand that all the elements in the first model need to be modeled again but in order to make the model easily deployable it may require some reorganization and subdivision by system or by project sections. The format of this second model is proposed and discussed in section 6.2.3 and 6.2.4

The LOD for this model even when is at a 500 level, defined by the AIA as the level of development that contains information for facilities management (AIA 2013), does not require a high level of detail in the objects graphic representation.

The next stage in the project lifecycle is the operation and maintenance. This stage begins with the setting up of the CAFM. The proposed model contains most of the information needed to set up the facility in terms of what is needed by the CAFM. The proposed approach allows for two different ways to conduct the set-up. The first one uses a tabular schedule file, as the one showed in table 6 below, which includes a list of the attributes described in the sections 6.2.3 and 6.2.4, this information can be entered or directly imported (if the CAFM has that capability) in the CAFM. The second option is to generate a COBie file; the proposed approach is a based on the same subset of the IFC specified by COBie therefore, most of the information needed to generate the COBie spreadsheet is already in the model. However it needs to be organized in the COBie format, this is useful if the CAFM is capable of reading COBie files. The main advantage derived from the proposed approach is that the information is already centralized, organized and verified. This is extremely helpful for the initial setting of the facility in the CAFM.

Table 6 Excerpt of a schedule for spaces

Level	Number	Name	Area	Floor Finish	Department	FICM Classification	Capacity	Space Utiliz
Level 1	101	Office	128.78	Carpet	Career Development Centre	310 Office	1	128.78
Level 1	102	Office	140.93	Carpet	Career Development Centre	310 Office	1	140.93
Level 1	103	Office	129.13	Carpet	Career Development Centre	310 Office	1	129.13
Level 1	104	Office	235.44	Carpet	Career Development Centre	310 Office	1	235.44
Level 1	105	Office	132.37	Carpet	Career Development Centre	310 Office	1	132.37
Level 1	106	Corridor	278.5	Carpet	Career Development Centre	W06 Public Corridor	0	
Level 1	106-A	Interview Room	78.66	Carpet	Career Development Centre	315 Office Service	1	78.66
Level 1	106-B	Interview Room	79.31	Carpet	Career Development Centre	315 Office Service	1	79.31
Level 1	106-C	Interview Room	79.41	Carpet	Career Development Centre	315 Office Service	1	79.41
Level 1	106-D	Interview Room	74.17	Carpet	Career Development Centre	315 Office Service	1	74.17
Level 1	106-E	Interview Room	74.31	Carpet	Career Development Centre	315 Office Service	1	74.31
Level 1	106-F	Office	73.93	Carpet	Career Development Centre	310 Office	1	73.93
Level 1	106-G	Office	73.46	Carpet	Career Development Centre	310 Office	1	73.46
Level 1	107	Student Worker Office	143.14	Carpet	Career Development Centre	310 Office	6	23.86
Level 1	108	Kitchen	194.52	Carpet	Career Development Centre	315 Office Service	0	
Level 1	109	Graduate Assistant Office	80.72	Carpet	Career Development Centre	310 Office	2	40.36
Level 1	109-A	Storage Closet	190.19	Concrete	Career Development Centre	780 Unit Storage	0	
Level 1	110	Electrical Closet	27.11	Carpet	Career Development Centre	Y04 Utility/Mechanical Space	0	
Level 1	111	Toilet	188.97	Vinyl Tile	Career Development Centre	X03 Public Rest Room	0	
Level 1	111-A	Storage Closet	37.94	Vinyl Tile	Career Development Centre	780 Unit Storage	0	
Level 1	113	Utiliy Closet	41.84	Vinyl Tile	Career Development Centre	Y04 Utility/Mechanical Space	0	
Level 1	NA	Copy Room	93.6	Carpet	Career Development Centre	315 Office Service	0	
Level 1	NA	Stairs	99.84	Vinyl Tile	Career Development Centre	W07 Stairway	0	
Level 1	NA	Toilet	33.15	Vinyl Tile	Career Development Centre	X03 Public Rest Room	0	
Level 1	NA	Corridor	94.46	Vinyl Tile	Career Development Centre	W06 Public Corridor	0	

The process map also shows the use of the model for the support of the space management process. This is particularly helpful for this process because of the visualization power of the BIM model, two dimensional floor plans with color coded representation gives a different perspective on the information in relation with a tabular report (See figure 20 in section 5.1). Interrogating the model by click on a space and retrieve its properties is easier, quicker. Also is less probable to retrieve information for the wrong space in comparison with just using the room number as the entry key for information retrieval. Also the model is capable to show information on the windows, door and covering of the elements surrounding the space, which can also be used for maintenance.

6.2.3 Information exchange requirements and functional parts

The information exchanges requirements are the sets of information that support some activities of the process at a particular stage. An exchange requirement is intended to provide a description of the information in non-technical terms. These are identified in each of the process maps for the Space Management and for the Operation and Maintenance processes. There are specific information requirements for the delivery of the four models at the progressive completion of the four project development stages. These are; one model at the end of the schematic design stage, one at the end of the design development stage and the last two models at the end of construction as previously explained. The delivery of each of these models creates the need for defining the information exchange for their proper delivery and future use. In that way the exchange requirements are directly associated to the model delivery. As a consequence there are four corresponding exchange requirements for each process, These are shown in Figure 37 below are in more detail in Appendix C

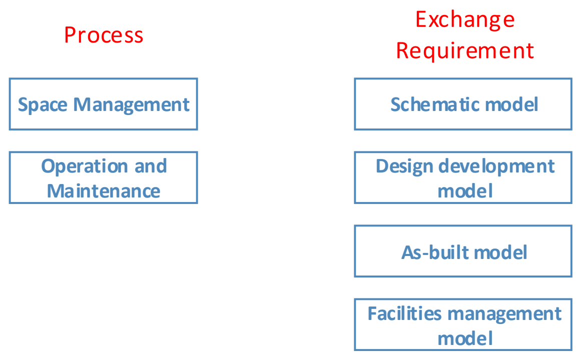

Figure 37 Chart of the exchange requirement for the Space Management and Operations and Maintenance processes

As it was showed in figure 33 each exchange requirement is supported by functional parts, which are units of information or a single information packages. The information requirement describes the information needs in terms of the required capabilities of the information model to provide such information. To exchange a model of a building, it is first necessary to model its elements, such as walls, floor, roofs, windows, doors and so on. The action of modeling these components is defined by the functional parts. Functional parts are implemented through the concepts of a model view definition. For this research the model view definition selected, was the IFC Basic-FM Handover View (Building Smart International, 2010b) which is a subset of the IFC 2x3 standard (Building Smart International, 2006). The reason to select this MVD is that the IFC is currently the most supported open standard. Also, the same MDV is used by the COBie specification, which is required for some governmental and private organizations; therefore, having the same basis makes it possible to create the COBie files with the information in the model using the exchange requirements proposed in this research.

The Basic-FM handover view inherits the support of the IFC 2x3 coordination view, which specifies the basic exchange requirements for the architectural, structural and MEP components. The Basic-FM adds functionality to the coordination view specifying the information needed for the specific use of the facilities management process. The IFC 2x3 coordination view (Building Smart International, 2010a) is not discussed in this document as is well documented by the Building Smart International Alliance for Interoperability. The concepts for the architectural, structural and MEP elements are not shown in the exchange requirements for the proposed approach; their definition conforms to the IFC 2x3 coordination view.

Schematic model exchange requirement has the same functional parts for both processes, that is, the Space Management and Maintenance and Operation as it is shown in Figure 38 below and in Appendix C.2. The functional parts are related to the general information of the project and building, as well as to the main definitions of the schematic design such as the location of the building in the site, the stories of the building, the spaces and zones.

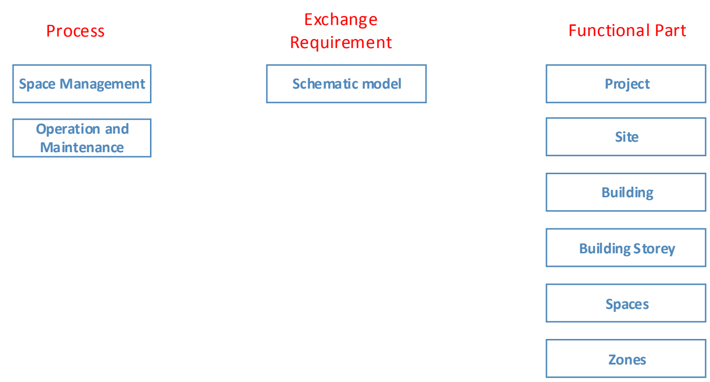

Figure 38 Functional parts for the Schematic Model exchange requirement

Figure 39 below (also shown in Appendix C.3) shows the functional parts corresponding to the Design Development Model, As-built Model and Facilities Management Model for the Space Management process, functional parts in this Exchange Requirements includes in addition to the functional parts of the Schematic Design Model the Doors, Windows, Coverings and Furnishings, this components are defined in the Design Development Model and updated as the model progress during construction and operation.

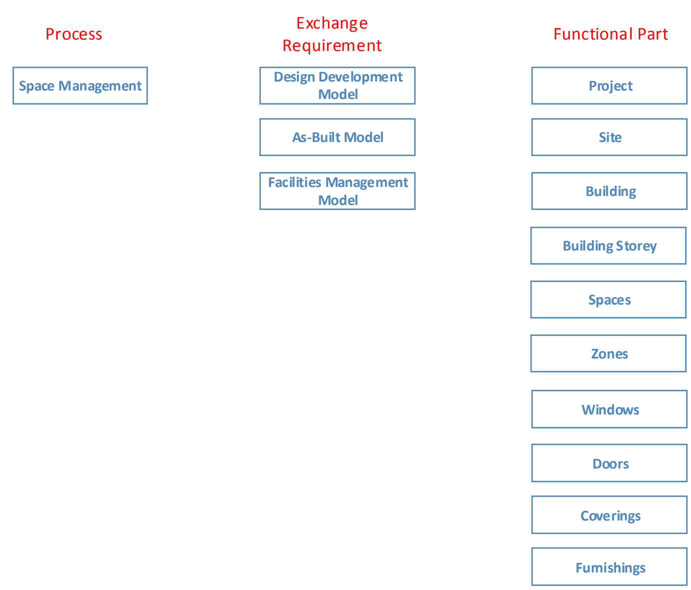

Figure 39 Functional parts for the Design Development Model, As-Built Model, Facilities Management Model exchange requirements, for the Space Management Process

Figure 40 below (also shown in Appendix C.4) show that the Operation and Maintenance process requires in addition of the functional parts for the Space Management, all of the information related to the MEP systems of the building

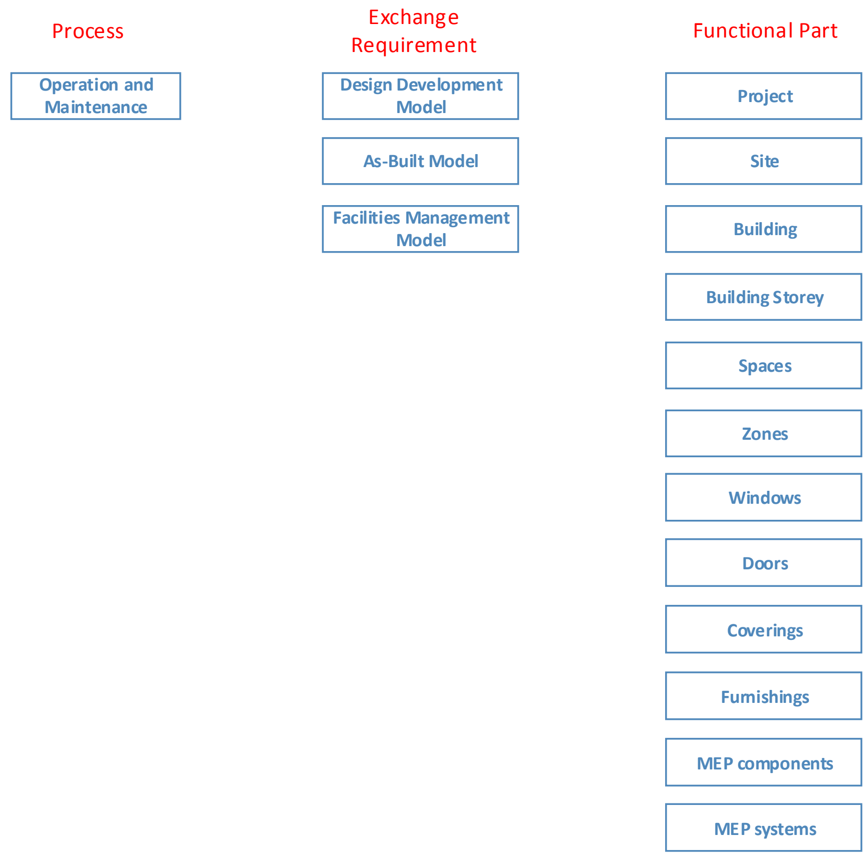

Figure 40 Functional parts for the Design Development Model, As-Built Model, Facilities Management Model exchange requirements, for the Operation and Maintenance Process

However, even when functional parts are common to some exchange requirements or processes, the concepts bindings which each process and exchange requirement are different The charts shown in Appendixes C.5 to C.16 use color coding to show the concept bindings relating its corresponding application to process and/or exchange. Figure 41 below is an example of how the color code is used. In this case the concepts (attributes) for the functional part MEP are shown on the right column. The colored circles at the right of each box indicate to what processes this concept apply. In this example none of the concepts apply to the space management process (yellow color code), and the concepts from "reference" to "year of production" apply only for the "Design Development Model" (blue color code) whereas all concepts apply to the "As-Built Model" and the "Facilities Management Model" This is so because is not until after installation of the MEP components that this information is available.

The concepts bindings are the ones directly related with the workflow of the facilities management staff, were derived from the literature review and from the case study conducted in this research. These are the considered to be essential and its inclusion in the models for facilities management is considered mandatory.

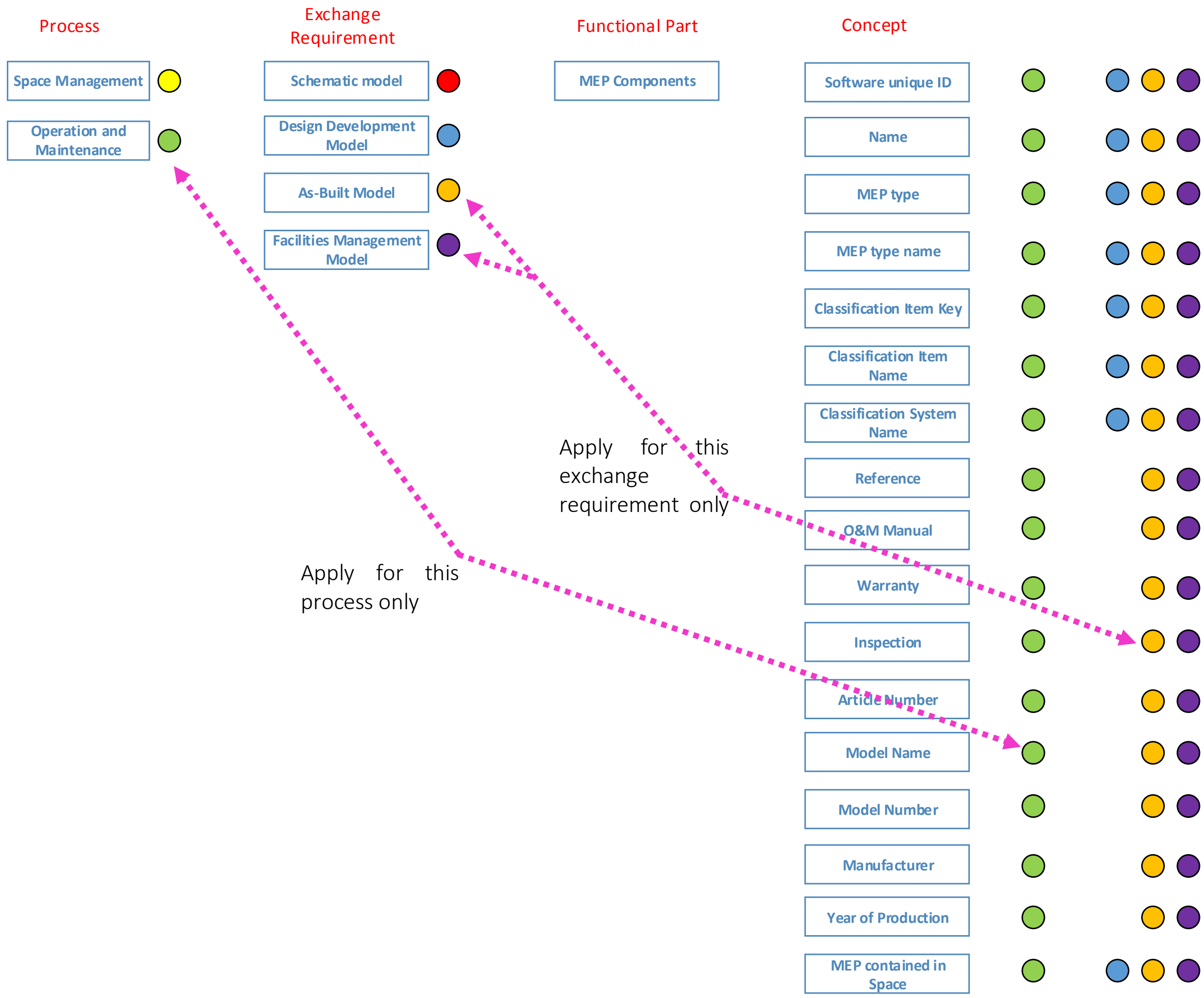

Figure 41 Example of the concepts for the MEP components functional part

6.2.4 Concept bindings

The information attached to the components in the model is integrated according to a proposed concept and concept binding. Figure 42 below shows a section of the long table shown in Appendix D It lists the functional parts, the concept or attribute and the concept binding in the form of the IFC model representation. The table includes a short description of the information the concept will record.

Object type / Group / Attribute	Definition	IFC Model Representation	Defined by
Project		ifcProject	
Project Attributes			
Software unique ID	Object identifier, to identify the software object	ifcProject.GlobalID	Software
Number	User assigned number or ID	ifcProject.Name	User
Name	User assigned name	ifcProject.LongName	User
Project Units			
Length unit	Default unit for all the length measures in the data set	ifcProject.UnitsInContext	User
Area unit	Default unit for all the area measures in the data set	ifcProject.UnitsInContext	User
Volume unit	Default unit for all the area measures in the data set	ifcProject.UnitsInContext	User
Project Decomposition			
Site contained in project	Link to the top level node of the spatial structure. Being a site.	ifcRelAggregates	Software
Building contained in project	Link to the top level node of the spatial structure. Being a building.	ifcRelAggregates	Software
Site		ifcSite	
Site Attributes			
Software unique ID	Object identifier, to identify the software object	ifcSite.GlobalID	Software
Number	User assigned number or ID	ifcSite.Name	User
Name	User assigned name	ifcSite.LongName	User
Site Address			
Address	Address lines	ifcSite.Address.AddressLines	User
City	City name	ifcSite.Address.Town	User
State	State name	ifcSite.Address.Region	User
Zip	Postal Code	ifcSite.Address.PostalCode	User
Spatial Decomposition			
Site contained in project	Backlink to the project as highest node in the project structure	IfcRelAggregates with RelatingObject = IfcProject	Software
Building contained in project	Reference to all buildings that are situated in this site.	IfcRelAggregates with RelatingObject = IfcBuilding	Software
Building		ifcBuilding	
Building Attributes			
Software unique ID	Object identifier, to identify the software object	ifcBuilding.GlobalID	Software
Number	User assigned number or ID	ifcBuilding.Name	User
Name	Designer assigned name	ifcBuilding.LongName	User
Building Address (only if there is no site)			
Address	Address lines	ifcBuilding.Address.AddressLines	User
City	City name	ifcBuilding.Address.Town	User
State	State name	ifcBuilding.Address.Region	User
Zip	Postal Code	ifcBuilding.Address.PostalCode	User
Building Properties			
Age	Year of construction	IfcPropertySingleValue (Pset_BuildingCommon, YearOfConstruction)	User
Landmark Status	Landmark or not	IfcPropertySingleValue (Pset_BuildingCommon, IsLandmarked)	User
Spatial Decomposition			
Building contained in project	Backlink to the project as highest node in the project structure	IfcRelAggregates with RelatingObject = IfcProject	Software
Building contained in site	Either contained in a site, or if no site is available, directly in the project	IfcRelAggregates with RelatingObject = IfcSite	Software
Building Storey contained in building	Storeys in the building, should be at least one storey		Software

Figure 42 Excertp of the Concepts Bindings Definition Table

The complete table shown in Appendix D includes all of the concepts included in the Basic-FM handover model view definition, which is a subset of the IFC and that have to be complimented with the Coordination Model View Definition for the basic architectural, structural and MEP concepts. The concepts included in the complete table are:

- Project
- Site
- Building
- Building Storey
- Space
- Coverings
- Window
- Door
- Furnishing

- Building Service Elements (MEP)
- Proxy
- Zone
- System

The project, site and building, and building storey are not components with modeled geometry, those are information and organization components for the facility, contain information regarding the facility and how the components are organized. Site is optional, but it has to be indicated and some information about the site can be attached to the project or building.

Space is one of the first components defined in the model, those are initially defined with the architectural programming during the planning stage, and is one that in each of the subsequent stages new attributes should be added to it, as was explained in sections 6.2.2 and 6.2.3 ,

Figure 43 below illustrates a section of the complete table shown in the Appendix D. on the table there are some concepts or attributes highlighted in purple color, this color code was used to differentiate these attributes from those that are not included in the Basic-FM Handover Model View Definition.

Object type **Group** **Attribute**	**Definition**	**IFC Model Representation**	**Defined by**
Zone as a logical grouping of spaces		ifcZone	
Zone Attributes			
Software unique ID	Object identifier, to identify the software object	ifcZone.GlobalID	Software
Name	Individual element name	ifcZone.Name	User
Spatial Zone Assignment			
Grouping of system components			
Spaces assigned to zone	Assignment of individual spaces that belong to the zone for organizational or other purposes	IfcRelAssignsToGroup with .RelatingGroup = IfcZone, and .RelatedObjects = all IfcSpace's belonging to the zone	User
System as a logical grouping of components		ifcSystem	
System Attributes			
Software unique ID	Object identifier, to identify the software object	ifcSystem.GlobalID	Software
Name	Individual element name	ifcSystem.Name	User
System Classification			
Classification	System classification	IfcClassificationReference (through relationship IfcRelAssociatesClassification)	User
Classification Item Key	Key of classification item within the classification system	IfcClassificationReference.ItemReference	User
Classification Item Name	Clear name of the classification item	IfcClassificationReference.Name	User
Classification System Name	Name of the classification system	IfcClassification.Name (through IfcClassificationReference.ReferencedSource)	User
System Properties			
System common properties	**Properties that are specified in the standard property definitions (or a relevant subset of)**	**IfcPropertySet with Name = "Pset_SystemCommon"**	
Reference	Reference ID for this specific instance	IfcPropertySingleValue with Name = "Reference"	User
FCA index	**Facility condition assessment index**	**IfcPropertySingleValue with Name = "fcaIndex"**	**User**
FCA Cost	**Facility condition assessment cost**	**IfcPropertySingleValue with Name = "fcaCost"**	**User**
FCA priority	**Facility condition assessment priority**	**IfcPropertySingleValue with Name = "fcaPriority"**	**User**
FCA maintenance program	**Facility condition assessment maintenance program**	**IfcPropertySingleValue with Name = "fcaProgram"**	**User**
O&M Manual	**url link to the O&M documentation**	**IjcPropertySingleValue with Name = "OperationAndMaintenance"**	**User**
Warranty	**url link to the warranty documentation**	**IjcPropertySingleValue with Name = "Warranty"**	**User**
Inspection	**url link to the inspection/startup documentation**	**IjcPropertySingleValue with Name = "Inspection"**	**User**
Component System Assignment			
Grouping of system components			
Components assigned to system	Assignment of individual components that belong to the MEP system	IfcRelAssignsToGroup with .RelatingGroup = IfcSystem, and .RelatedObjects = all components (subtypes of IfcDistributionElement) belonging to the system, or IfcSystem's being sub-systems	Software
System Services Buildings			
System assigned to building structure	Assignment of the system to the level of the building structure, it serves	IfcRelAssignsToGroup with .RelatingGroup = IfcSystem, and .RelatedBuildings = levels of the building structure	Software
System assigned to story	Assignment of the system to the level of the story, it serves (horizontal and single story systems)	with .RelatedBuildings = [1...n] IfcBuildingStorey	Software
System assigned to building	Assignment of the system to the level of the building, it serves (Vertical systems)	with .RelatedBuildings = [1...n] IfcBuilding	Software
System assigned to site	Assignment of the system to the level of the site for delivering services to the building	with .RelatedBuildings = [1...1] IfcSite	Software

Figure 43 Sample of the color code for identifying the new concepts of the proposed approach

However, these attributes are of common use during operation and construction. In the case study conducted in this research, these attributes were found to be part of the main set of information for the space management process, not only for the facilities management staff, but also for the provost office staff. The later office is in charge of monitoring cost indexes for the utilization of facility space. The concept binding definition of these items follows the same IFC standard and the use of the properties set extensibility of the IFC scheme. Therefore, these are in compliance and fully supported by the IFC standard. These new proposed concept or attributes are:

- Capacity. *Capacity of the space (if designed to host users).*
- Department. *Organization's department whose space is assigned to.*
- Space utilization Index. *Calculated with the full time equivalent students/faculty and the assignable area.*
- Occupant. *Name of permanent occupant of the space.*
- Maintenance Cost. *Cost of maintenance related to the space.*
- Lease Cost. *Lease charges for the use of the space.*
- Operation Cost. *Cost of utilities and other services for the space operation.*

The newly defined attributes follow the IFC convention and are defined using the ifcPropertySet binding.

In addition to the standard set of attributes on the Basic-FM handover model view, three new attributes have been defined for Coverings, Windows, Doors, Furnishings, MEP and Systems functional parts:

- O&M Manual. *url link to the O&M documentation.*
- Warranty. *url link to the warranty or guarantee documentation.*
- Inspection. *url link to the inspection/startup documentation.*

This is information that is essential for the operation and maintenance of a facility and is not commonly attached to any information system. The proposed approach attaches this information as a link to the URL address where the digital file is stored. Therefore these files can be stored in whatever server space (local or cloud service) is convenient for the facilities management The main advantages offered with this approach is the centralization an uniqueness of the entry point for retrieving the information, which is contained within the model. This approach of linking information to the visual display of the model is not possible when using text or tabular only search methods.

As part of the proposed approach for the System functional part, another set of attributes is defined:

- FCA index. *Facility condition assessment index.*
- FCA Cost. *Facility condition assessment cost for retrofitting or replacement.*
- FCA Priority. *Facility condition assessment priority, according to organization policies.*
- FCA Maintenance Program. *Facility condition assessment program under this maintenance is categorized.*

This is part of the facility condition assessment and is useful for financial planning and master program definition of the campus.

6.3 Technical validation

As it was mentioned in the methodology the validation of the approach was done in two parts. The first part validated the technical feasibility of the proposed approach. It consisted in creating a proof of concept by applying the proposed approach to a model of a facility; the second part consisted of an online a survey distributed to colleges and universities around the nation as well as conducting selected personal interviews with facilities management executive staff of colleges in the local area. The latter part has been documented in section 5.4 of this report.

6.3.1 Proof of concept

The proof of concept consisted in applying the proposed approach to a model of a facility. The facility selected was the Sports and Recreational Center at WPI, this facility was part of one of the case studies of this research. The information handed over on this project was available from the project construction manager, as well as from the model created provided by the designer who used the model only for the purposes of project visualization and presentation as well as for the production of coordinated 2D construction documents.

Once the model was created for the above purposes it was not updated with the latest changes that occurred during the construction stage. However, the model was facilitated to the construction manager who used it to integrate 3D models from the MEP and Fire Protection subcontractors to conduct a clash detection exercise among these trades. In doing so, the final geometry of the building was updated but in a different file format.

The original model was updated by the researcher who modified the original room numbering assigned by the designer system to reflect the final assignment of room numbers assigned by the owner. Another modification made to the final model included a change in a ramp location and some minor layout differences. The mechanical, electrical and piping systems were left as originally created in the model although these modifications were captured in the construction manager 3D coordinated model.

The level of development of the model is something between 200 and 300 according to the last definition of the AIA (American Institute of Architects 2013), the level of detail is higher than the required for the facilities management purposes This LOD was preserved in the updated model. Some of the elements not required for facilities management were filtered out. Some of these included structural elements, and all of the model lines representing signage. This step created a lighter version of the model for facilities management purposes.

The model parameters were modified following the exchange requirement charts and the concept bindings proposed and included in this document on the Appendixes C and D. The model was originally created by the building designers using Autodesk Revit 2010, and was converted by the researcher to the Autodesk Revit 2014 version. The attributes that were not part of the original standard parameter definition of the model were created by the researcher and attached to the model using the shared parameters feature of Revit, this is the only option that could be used with Revit in order to be able to export the parameters to the IFC version of the model. Also to the DWFx version of the model, which the format selected for the FM deployed model.

During the validation exercise all required attributes to support the facilities management process were created and attached successfully to the elements of the model. In order to test the functionality of the parameter in the IFC and the DWFx versions of the model it was necessary to add attributes carrying no information. Since null attributes are not exported by the BIM authoring tool, small number of elements in the model were populated with dummy information.

6.3.1.1 Proof of concept conclusion

A working proof-of-concept model was tested by registering the feedback from the WPI´s Facilities Department on the usability, applicability and convenience of using the model to support the facilities management process, particularly for the space management process.

In addition to that working proof of concept another mode available model were adjusted according to this research proposal. Figure 44 below shows a screenshot of the model of the Rec-Center at WPI as it was successfully structured with the added parameters in accordance with the IFC standard.

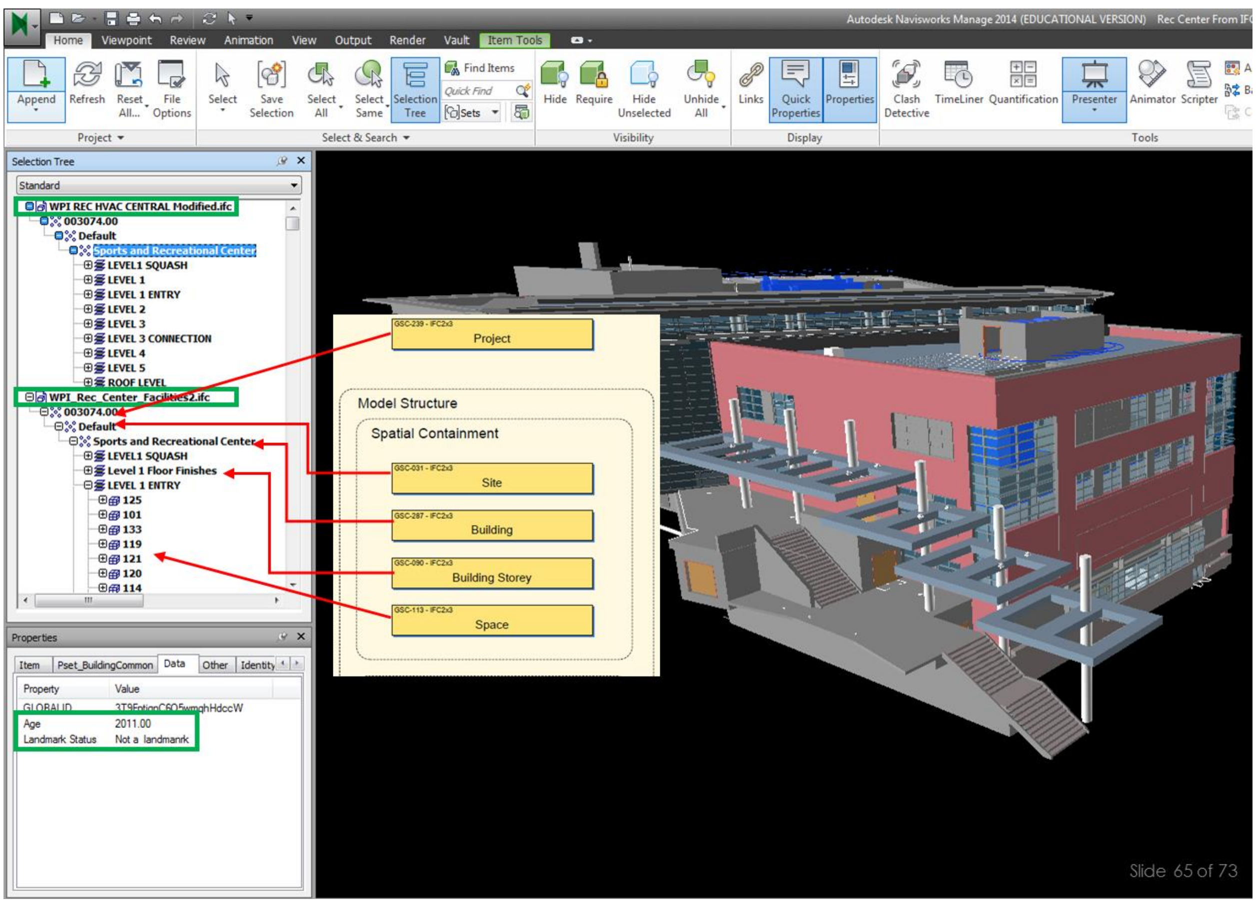

Figure 44 Screenshot of the Rec-Center model with attributes in compliance with the IFC standard

It was possible in this model to link PDF documentation of the warranties and operation and maintenance manuals, using the proposed extension of the FM-Basic Handover model view definition. See figure 45 below.

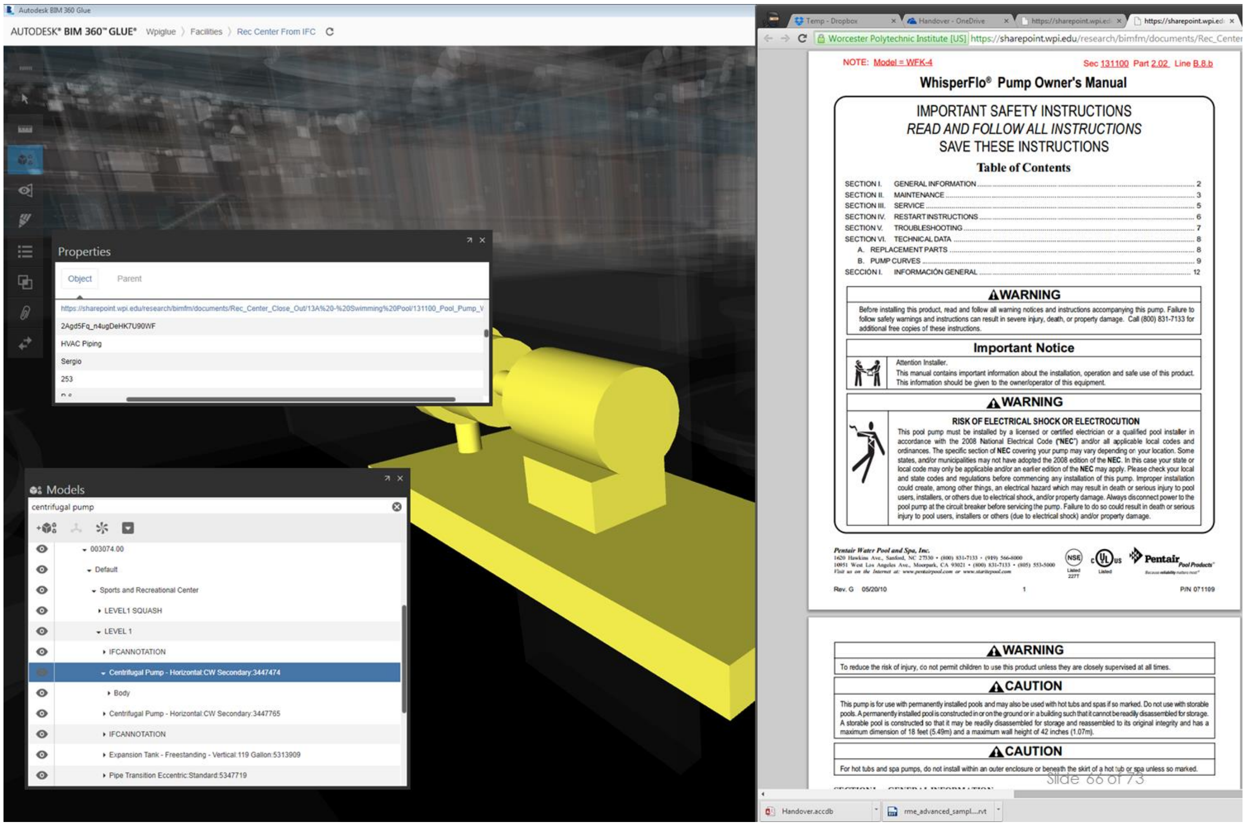

Figure 45 Screenshot of the model and the linked PDF warranty documentation

7 Conclusions and future work

The operation and maintenance of a constructed facility takes place after the construction is finished. It is usually the longest phase in the lifecycle of the facility and the one that substantially contributes to its lifecycle cost. To efficiently manage the operation and maintenance of a facility, the staff in charge needs reliable and timely information to support decision making throughout the facility's lifecycle. Most of this information is generated during the planning, design, and construction stages of the facility and usually delivered at the end of the construction.

The use of Building Information Modeling (BIM) is gradually but steadily changing the way constructed facilities are designed and built. As a result of its use a significant amount of coordinated information is generated during this process and stored in the digital model. However, once the project is completed the owner does not necessarily receive full benefits from it for future operation and maintenance of the facility. College and University institutions are making great advances on implementing BIM for the operation and maintenance stage. To-date, different approaches with different degree of success have been attempted to use BIM technology in the integration of information through the handover process. Some of these approaches consist of ad-hoc solutions, or implemented through somewhat non-open rigid commercial software solutions, or data specifications. However the general current interoperability issues including the lack of comprehensive development of open standards and the full support by software vendors to open standards still limit the full leverage that could be obtained through BIM technology for these purposes.

This research explored the information that in the context of educational facilities has value to the owner/operator and that can be delivered at the end of the construction stage through a BIM-enabled digital handover process for enhancing the operation and maintenance of the facility. To accomplish this objective, it conducted an extensive literature review and an in-depth case study of an academic institution examining in-depth its current practices and needs for the handover of information, operation and maintenance and space management requirements as well as of the future needs of the facilities management department information system generated by the use of BIM technology. It also discussed the importance of the Information Delivery Manual and Model.

This research proposes an open standard approach for the creation of a Model View Definition that combines Industry Foundation Classes (IFCs) with COBie standards or with Owner defined standards.

The proposed approach has the following characteristics:

- Defines a process to maintain a continuous workflow throughout the project lifecycle that ideally should be implemented at the early stages when an architectural program is generated
- Identifies what information, having value for facilities management, is generated at each stage of the project lifecycle ;
- Proposes a formal open standard framework for the organization, manipulation, and integration of information into the BIM model that is related to the facilities management process
- Specifies the deliverables for each stage of each project lifecycle to maintain a continuous workflow throughout the project.

- Specifies a structured process for the creation of a “lean” BIM model for faculties management use.
- Establishes a procedure for the use of the BIM during the operations and maintenance stage that serves as a central source of information for retrieving and populating the computerized facilities management systems as well as the use of the model for supporting maintenance and the space management procedures.

The implementation of the proposed approach includes a document with guidelines for the development of a BIM model for the existing facilities, using the technology such as the laser scanning and photogrammetry to speed up the process. The current scope of the proposed approach can be extended by defining new attributes for elements as desired, following the guidelines of the model view definition (Appendix B and C) and concept bindings (Appendix D) proposed. Owners who intend to extend uses of BIM models for facility management purposes can use the specifications included in this proposal to formalize the information requirements for design and construction professionals in their projects. It is also expected that in the near future this approach could also be implemented by academic institutions as a requirement for the designer and contractor of future additions, renovations or new facilities.

The proposed approach can be implemented using current capabilities of commercial BIM authoring software; however this implementation should be in compliance of the model view definition proposed. Software vendors or developers can take into account the workflow and information requirements herein defined in order to provide better support to the designers, contractors and facility managers. Much of the information that has to be attached to a design-construction BIM model could be done automatically if the software provides that capability (as in the room in which an element is located, just to mention an example). However this is not currently the case of all of the mayor commercial vendors. Better support can also be provided by software vendors by the creation of better and easier to use IFC translators. This will properly guarantee the interoperability and deployment of the data transfer.

As a result of this work owners can reap the benefits of implementing a reliable automated electronic exchange of information process that integrates in an efficient way the delivery of design and construction information for the long term operation and maintenance of the project, making the facility management process more efficient.

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Appendix A. Guidelines for creating a model of an existing facility.

Every day is more common that new facilities projects, contain in certain degree the use of BIM in some degree, availability of models of this facilities is becoming a common characteristic of new projects. However, the major proportion of the current facilities stock were created in the pre-BIM era, therefore the benefits of having a model for the use during the operation and maintenance stage is not possible.

The benefit of a BIM model for the use on the operation and maintenance stage is usually good enough to justify the creation of a BIM model for the existing facility.

This section described an approach to create BIM model of existing facilities for its use during operation and maintenance.

A.1 What is the model for?

The first step is to decide is what the model is for. There is two major purposes for the model one is space management and the other is maintenance.

It is very likely that maintenance is already running on a computerized system in the organization, if that is the case, maybe creating a model for the support of maintenance is not enough justification for creating the model, it is needed to define what would be the value of the model. However, currently the facilities management computerized system cannot offer some of the main characteristics of the BIM, such as the space awareness, therefore weighting the value of having the model should be done. Space management is more natural to BIM that any current facilities management system, however weighting the options should always be done.

A.2 What to include?

Second step is defining what should be modeled. In this document are included guides to determine what components apply to what use (Appendix C) and what attributes can be attached to the elements (Appendix D).

This will define what elements to model and at what level of development and detail. Including elements that its information will not be used add no value to the model and should be avoided. The elements modeled are gross representation, unless some geometrical calculations needed on the element, the level of detail are usually coarse.

An important factor to have in consideration is that creating the model is just the beginning. The model should also be maintained, when a renovation, addition or any physical modification on the facility should modify the model to be updated which imply having the skills, time and effort to make modification to the BIM, therefore prioritize components or system that do not often suffer physical changes.

The information attached to the model should also be maintained, however, maintenance of the attached information is no more difficult than in any other CAFM.

A.3 Creating the model with available drawings

The preferred starting point to create the models is the existing drawings of the facility, is very likely those exist because are a fundamental piece of information for facilities management. Existing drawings usually are available as a digital CAD drawings, PDF versions or printed paper versions. If the last is the case is highly recommendable to convert those to PDF using a scanning service provider.

It is always recommended first to start creating the architectural/structural model, and after the verification of the accuracy of the model in relation to the actual facility, model the MEP components.

A.3.1 Starting the model using CAD drawings.

If CAD drawings are available, those can be inserted in the BIM authoring software to use it as a reference, the scale can be adjusted if necessary. Using the drawings as reference, the model can be started modeling, walls, doors, windows, stairs, floors and roofs. (or MEP equipment if the architectural/structural model was verified)

If is a multistory facility it is common that the drawings have errors characteristic of a 2D representation approach, the error will arise when overlaying the drawings of the different stories of the facility, differences as the one in the figure 46 between some structural elements that should be common for different stories aren't. If this is the case is always better to work only selecting one story, select one that can be verified on the exterior dimensions. After verification the position the next story drawing looking for the best fit.

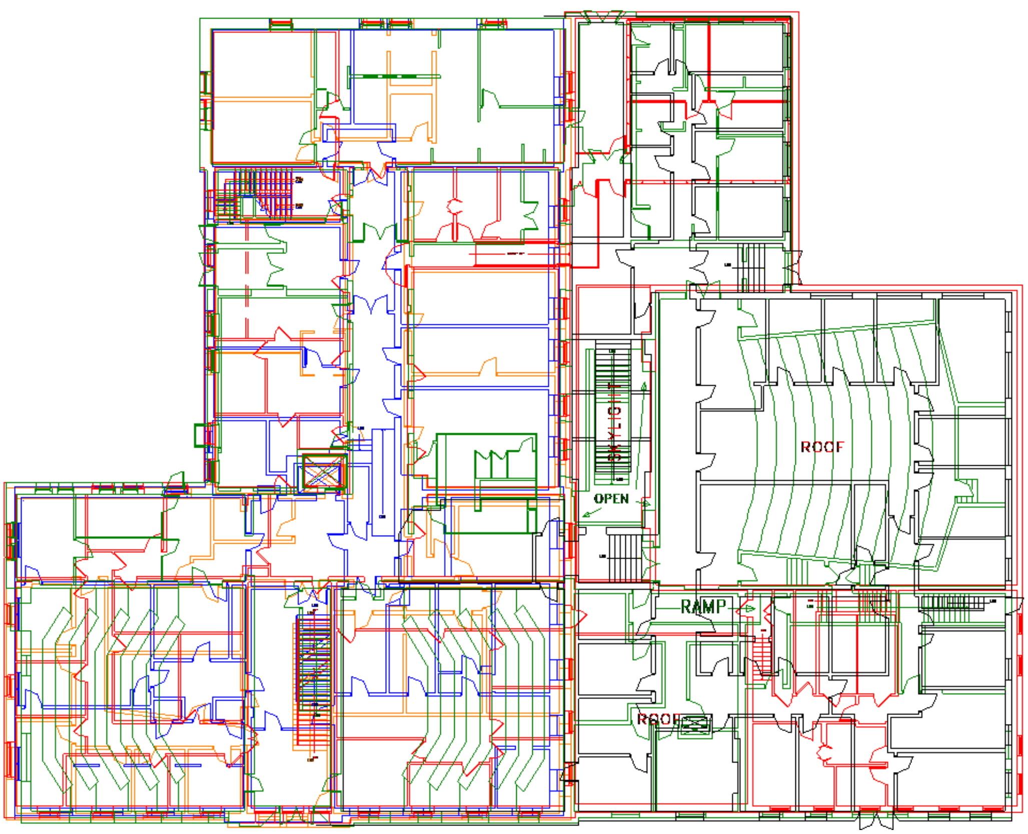


Figure 46 Sample figure with floor drawings overlaid

A.3.2 Starting the model using PDF versions or printed files.

If printed versions are the only alternative, then is better to scanning the drawings using a scanning service provider, using a 1:1 scanning scale.

The PDF can be inserted in the BIM authoring tools and the scale can be adjusted if necessary. If none of the standard scale works you can stretch the PDF, using a known dimension from the PDF take the measure with the BIM authoring appropriate tool, the is possible to use those dimension as a ratio for scaling the PDF.

If is a multistory facility it is common that the drawings have errors characteristic of a 2D representation approach, the error will arise when overlay the drawings of the different stories of the facility, differences as the one in the figure 46, between some structural elements that should be common for different stories aren't. If this is the case is always better to work only selecting one story, select one that can be verified on the exterior dimensions. After verification the position the next story drawing looking for the best fit.

A.3.3 Verification of the dimensions of the model

Usually the available drawings of the facility are out of date, is common the drawing do not reflect the actual status of the facility. Another common situation is the drawings, particularly for old buildings, do not have the accuracy to reflect the actual dimension of the facility, for the purposes of how this information is used the accuracy is good enough, however, for creating a model from this differences can complicate creating a model because the coordination of common element from story to story, therefore verification of the layout and dimension of the model should be done. This is made comparing the dimensions of the model with the actual dimensions of the facility.

Comparing dimensions is a challenging and time-consuming task, the most basic approach can be used or the most state of the art technology can also be used, in any case is a major task. If the accuracy of the model was not an issue when working with 2D drawings, then is recommended to reconcile measures for the common elements among stories, such as, structural columns, bearing walls, exterior wall, stairs and shafts. If accuracy is an issue the verification of the model can be done using some of the technics described in Appendix A

A.4 Creating the model without available drawings.

If not drawing are available there is no other option that to direct measure the facility. The following methods can be used for that purpose.

A.4.1 Manual method

Manual method implies the use of a measuring tape or a laser distance meter, a clipboard, paper and a pencil. Visit each room of the facility and taking the measurement using the paper and pencil to register the information. Sketching of the room needs to be done to have a reference of the measure. The measurement of the basic architectural elements includes:

- Distance from wall finish to wall finish. For every different wall layout in the room.

- Width and height of doors and windows.
- Sill height of windows.
- Distance from window opening to a corner or any reference to positioning the window.
- Stairs width, thread depth and height, number of steps, and distance to a wall for location reference.
- Clear height from floor finish to ceiling finish.
- Height from floor finish to next story floor finish.
- Floor and roof system thickness
- Wall thickness.

The thickness of the wall, floors, and roofs is one of the more challenging measures to gather as not always are accessible.

Exterior measurements is another challenging measure to take with manual methods, long distances compromises the accuracy with a manual device. Heights are also complex to measure.

MEP elements measurement consists in measure the imaginary surrounding box around the equipment, and a reference for location of the equipment. Measuring the equipment in detail is not usually justified. Piping measuring includes de length, diameter, and a reference for location.

A.4.2 Using mobile devices

Mobile devices are a good complement for the manual method, it allows to sketch and annotate for registering the data. There is application for taking photographs and annotate the dimensions directly in the photo, this is quicker than sketch. Another type of apps that can be used are the ones that uses the device camera to produce the sketch, entering a knowing measure the app adjust the remaining measures, the accuracy of this apps id not high, but sometimes enough for space management purposes. The real advantage of this kind of app is generate the sketch which saves time. Measuring the room and entering the dimension in the sketch can produce accurate drawings (Figure 47)

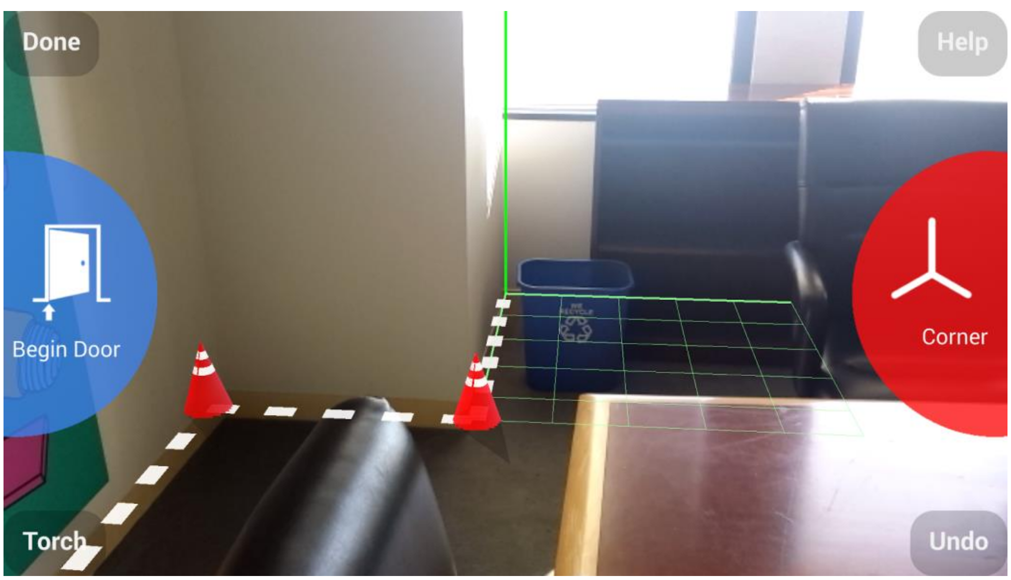


Figure 47 Sample Screen of the MagicPlan® app

A.4.3 Using photogrammetry

Photogrammetry is a technique who gained popularity when digital photography became accessible, it consist in post-process a photography to enable it for measuring. The accuracy can be fair enough for facilities management purposes. This technique is especially good for difficult element to measure such as skylights, height and length of exterior walls, windows not easy to reach.

The workflow consist in taking photograph of the element to measure and a measure of something that is included in the same frame. Then using specific software for this purposes, or other high end photo editors such as Adobe Photoshop, apply a correction to the distortion caused by the camera lenses, that will straighten the elements in the picture. Next apply a grid to the elements to measures taking into account the perspective caused by the vantage point of the picture. Adjust the scale of the grid and now the measures can be performed using the grid. (Figure 48)

Figure 48 Example of the photogrammetry technique

A.4.4 Using laser scanners

Laser scanning is the state of the art in measuring facilities, is an emerging technology, still expensive but very effective and accurate. It is performed by a device, shooting beams of light and measuring the distance and angle of the reflection of the light, the device can perform thousands of measures by second, each measure is a referenced point, that after post-processing can be combined in a point cloud creating a three dimensional representation of the facility formed by points.

Application to recognize physical elements from a point cloud are still in early stages of development, there is not still a single click application for converting the point cloud into building components, therefore still the best approach is to use the point cloud as a reference for creating the model in a BIM authoring software (see figure 49). The model produced with this approach have high accuracy. This is special convenient for modelling existing structures or piping systems, MEP elements, exterior envelopes of buildings, etc.

Figure 49 Sample Image of overlying the pint cloud for dimension verification

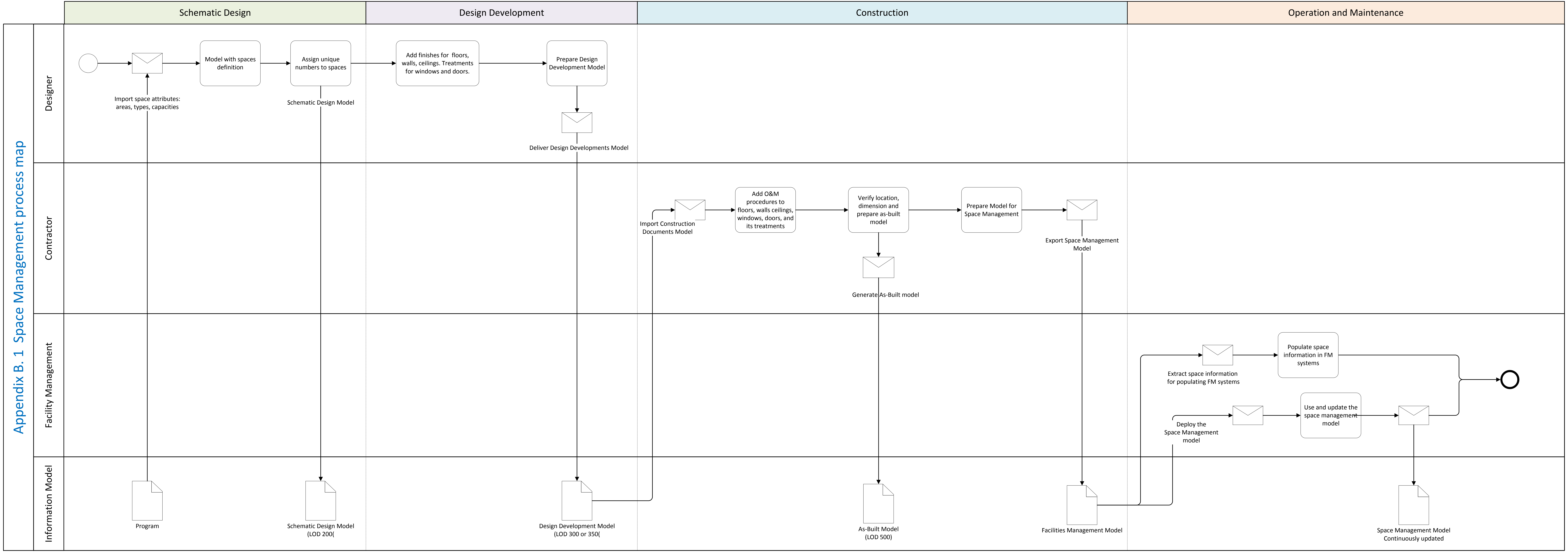
A.5 Attaching information to the model.

For attaching information to the model it first need to be gathered, if no drawings are available is very likely that the information needed won't be available either. In that case the information need to be gathered from the facility. Many of this information can be gathered at the same time the measurement are made. Floor finish, wall finish, window type, door type, space use, is really easy.

MEP equipment is challenging if the information needs to be gathered directly from the equipment, safety measures need to be taken.

Once the information is gathered it needs to be attached to the correspondent element in the model. Most of the authoring software have fields only for the standard attributes of the elements in the model. Facilities management information needs fields for attaching the attributes. Depending on the BIM authoring software is the method for creating this parameters in the model elements. Following the instruction of the software will allow to create the parameters and allow the element to receive this information. When creating the parameter take into account the type of information it will contain. Appendix D of this document contain the IFC concept binding for the attributes for facilities management.

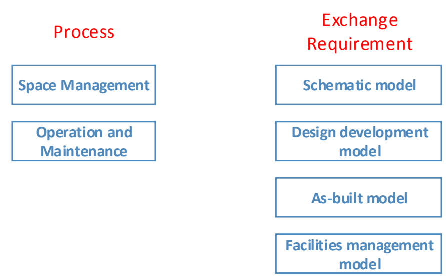
Appendix B. Process Maps


Appendix B. 1 Space Management process map
Schematic Design
Design Development
Construction
Operation and Maintenance
Designer
Contractor
Facility Management
Information Model
Model with spaces definition
Assign unique numbers to spaces
Add finishes for floors, walls, ceilings. Treatments for windows and doors.
Prepare Design Development Model
Import space attributes: areas, types, capacities
Schematic Design Model
Deliver Design Developments Model
Import Construction Documents Model
Add O&M procedures to floors, walls ceilings, windows, doors, and its treatments
Verify location, dimension and prepare as-built model
Prepare Model for Space Management
Export Space Management Model
Generate As-Built model
Extract space information for populating FM systems
Populate space information in FM systems
Deploy the Space Management model
Use and update the space management model
Program
Schematic Design Model (LOD 200(
Design Development Model (LOD 300 or 350(
As-Built Model (LOD 500)
Facilities Management Model
Space Management Model Continuously updated

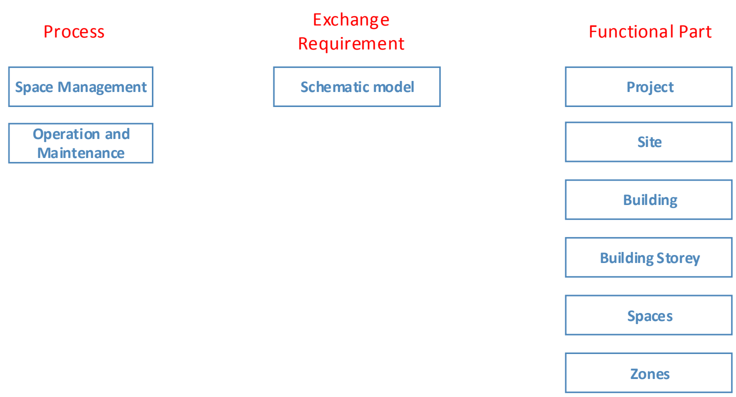
Appendix B.2 Maintenance and Operation process map

Appendix C. Exchange Requirements Charts

C.1 Exchange requirement for the Space Management and Operations and Maintenance processes.



C.2 Functional parts for the Schematic Model exchange requirement



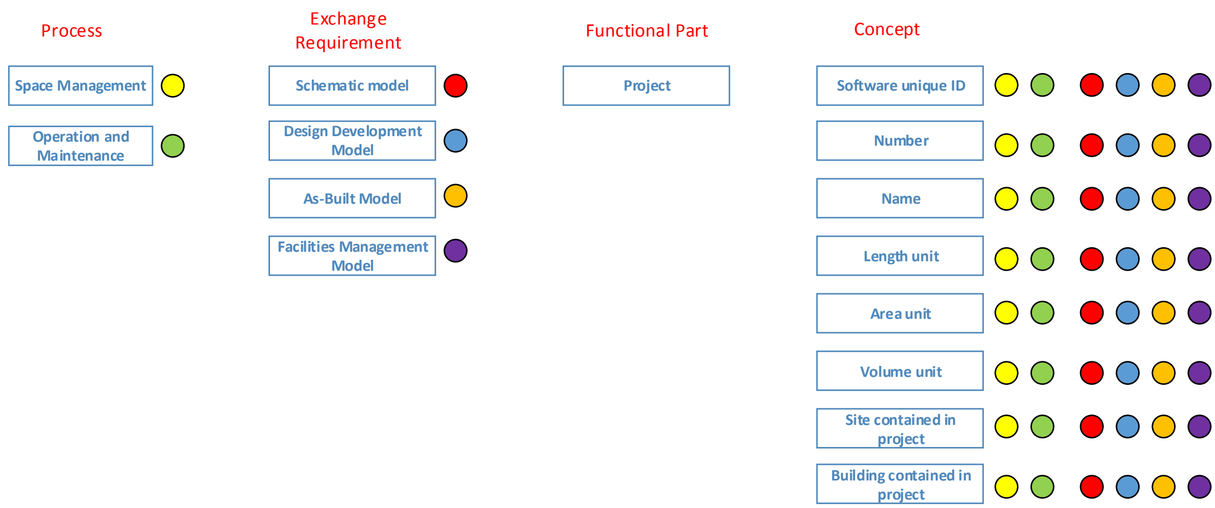
C.3 Functional parts for the Design Development Model, As-Built Model, Facilities Management Model exchange requirements, for the Space Management Process

Process	Exchange Requirement	Functional Part
Space Management	Design Development Model	Project
	As-Built Model	Site
	Facilities Management Model	Building
		Building Storey
		Spaces
		Zones
		Windows
		Doors
		Coverings
		Furnishings

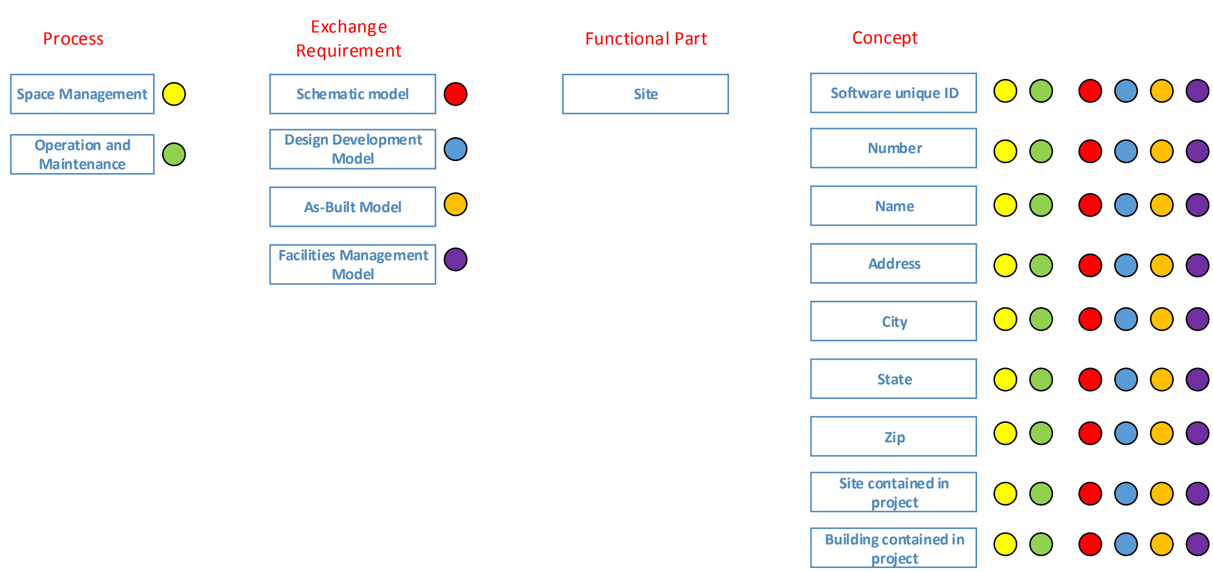
C.4 Functional parts for the Design Development Model, As-Built Model, Facilities Management Model exchange requirements, for the Operation and Maintenance Process

Process	Exchange Requirement	Functional Part
Operation and Maintenance	Design Development Model	Project
	As-Built Model	Site
	Facilities Management Model	Building
		Building Storey
		Spaces
		Zones
		Windows
		Doors
		Coverings
		Furnishings
		MEP components
		MEP systems

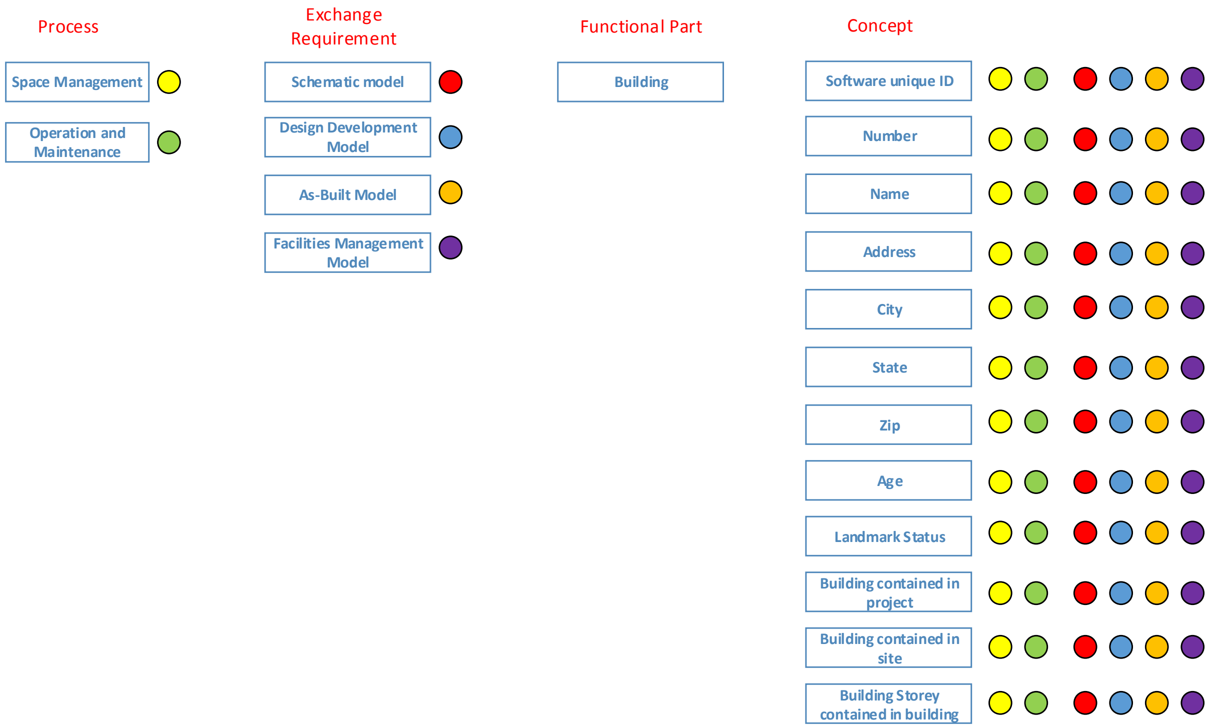
C.5 Concepts for the functional part Project



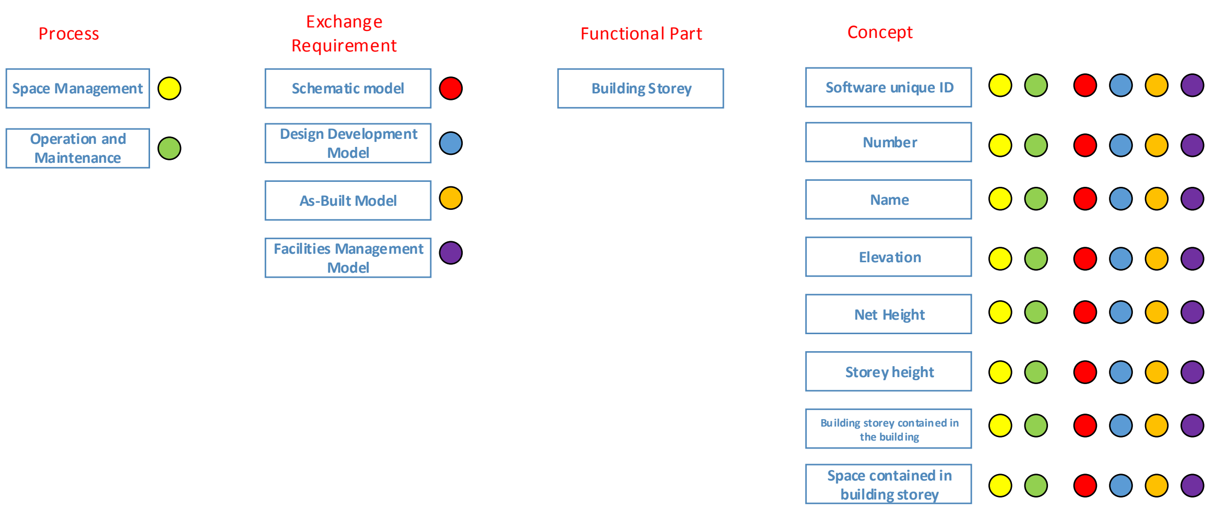
C.6 Concepts for the functional part Site



C.7 Concepts for the functional part Building



C.8 Concepts for the functional part Building Storey



C.9 Concepts for the functional part Spaces

Process

- Space Management (yellow)
- Operation and Maintenance (green)

Exchange Requirement

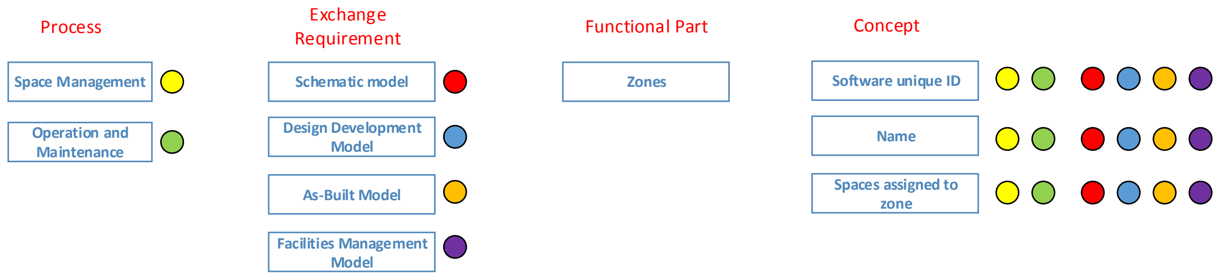
- Schematic model (red)
- Design Development Model (blue)
- As-Built Model (orange)
- Facilities Management Model (purple)

Functional Part

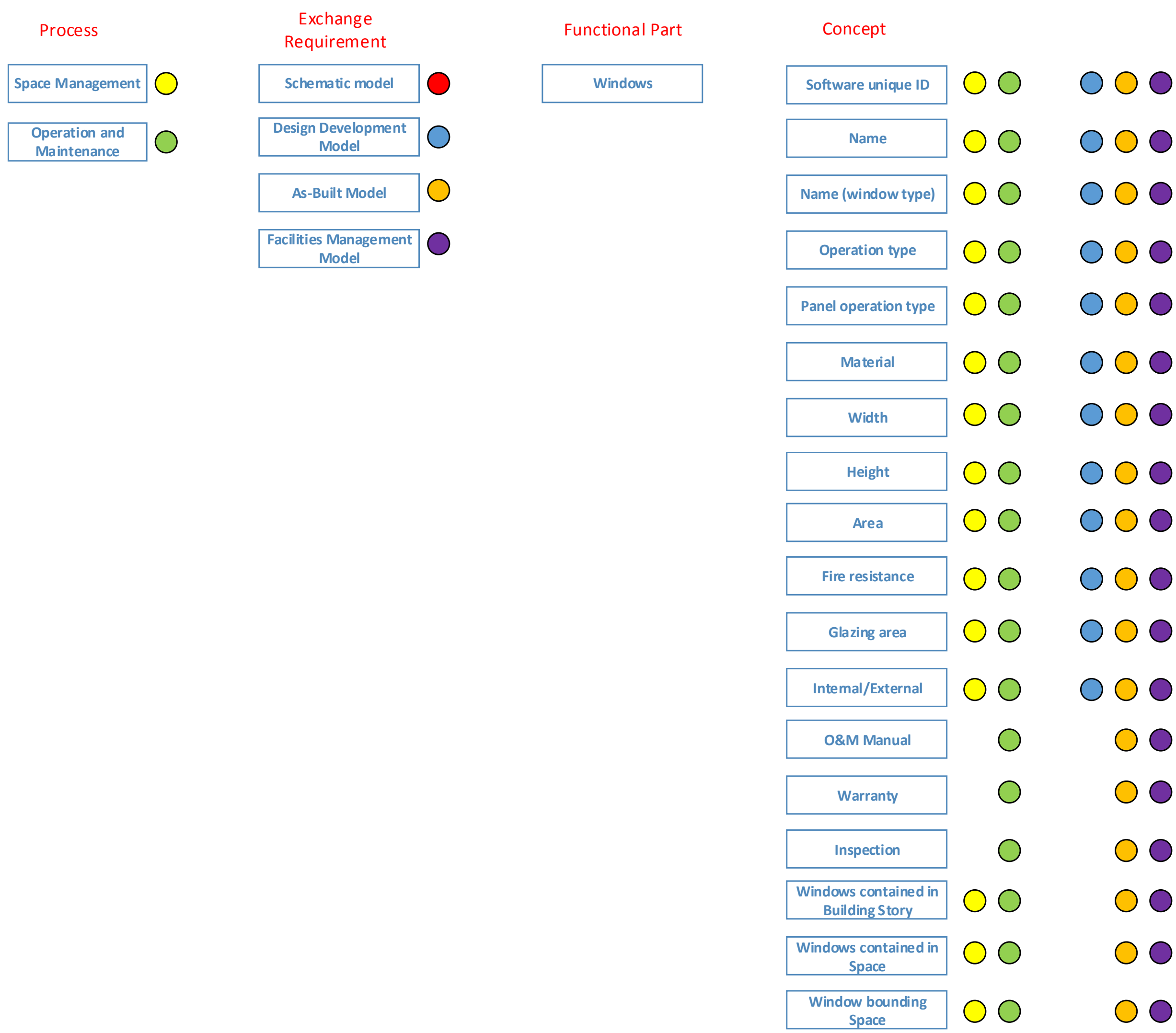
- Spaces

Concept	Space Management	Operation and Maintenance	Schematic model	Design Development Model	As-Built Model	Facilities Management Model
Software unique ID	●	●	●	●	●	●
Short Name	●	●	●	●	●	●
Long Name	●	●	●	●	●	●
Internal/External	●	●	●	●	●	●
Classification item key	●					●
Classification item name	●					●
Classification system name	●					●
FinishCeilingHeight	●	●		●	●	●
NetFloorArea	●	●	●	●	●	●
NetCeilingArea	●	●		●	●	●
NetWallArea	●	●		●	●	●
Flooring	●	●		●	●	●
Ceiling	●	●		●	●	●
Cladding	●	●		●	●	●
Capacity	●	●	●	●	●	●
Space contained in building storey	●	●	●	●	●	●
Department	●	●				●
Space Utilization Index	●					●
Occupant	●	●				●
Maintenance Cost	●	●				●
Lease Cost	●					●
Operation Cost	●	●				●
Space contained in Building Storey	●	●		●	●	●
Elements contained in Space	●	●		●	●	●
Coverings contained in Space	●	●		●	●	●
Doors/Windows contained in Space	●	●		●	●	●
Doors/Windows bounding Spaces	●	●		●	●	●

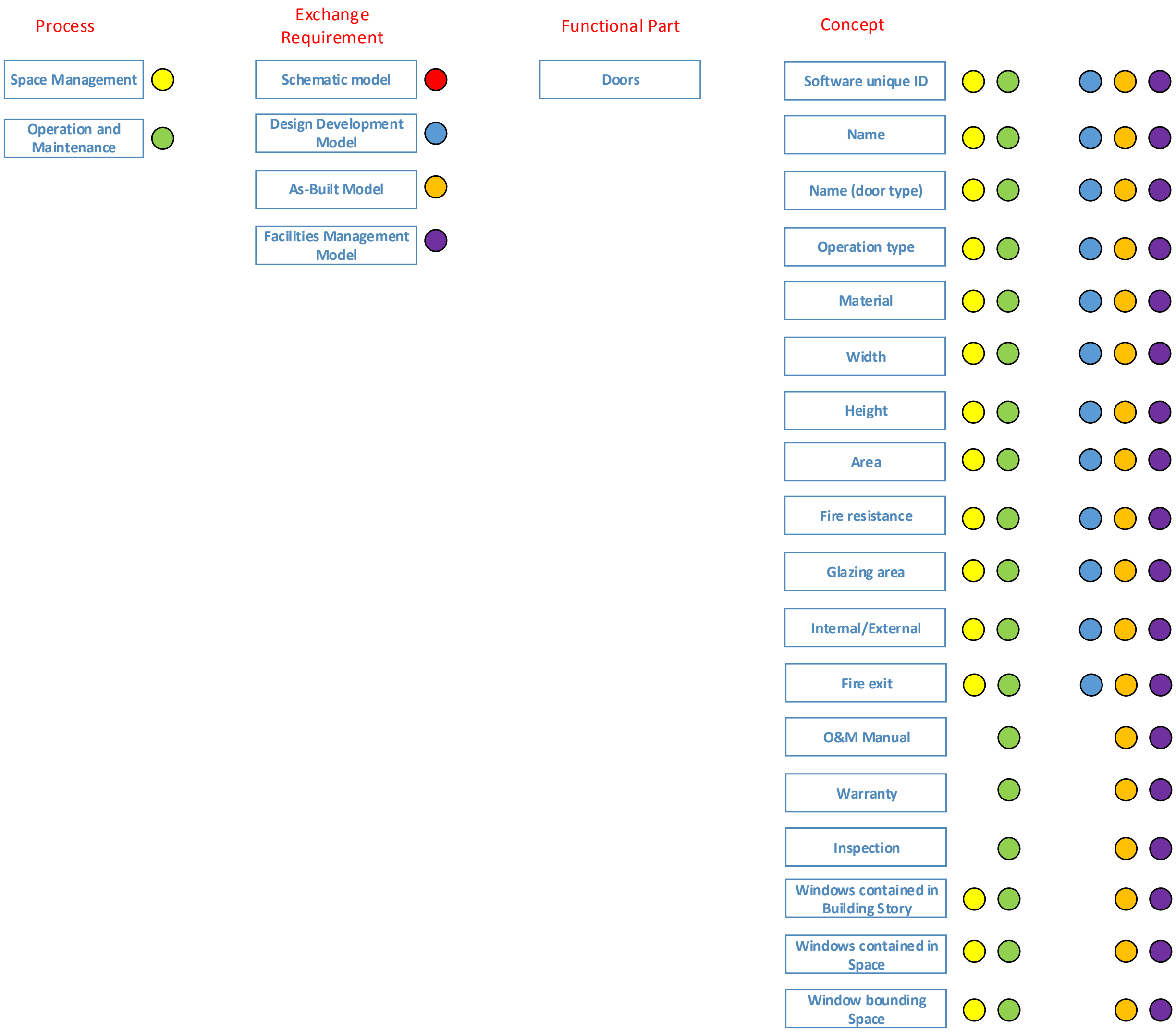
C.10 Concepts for the functional part Zones



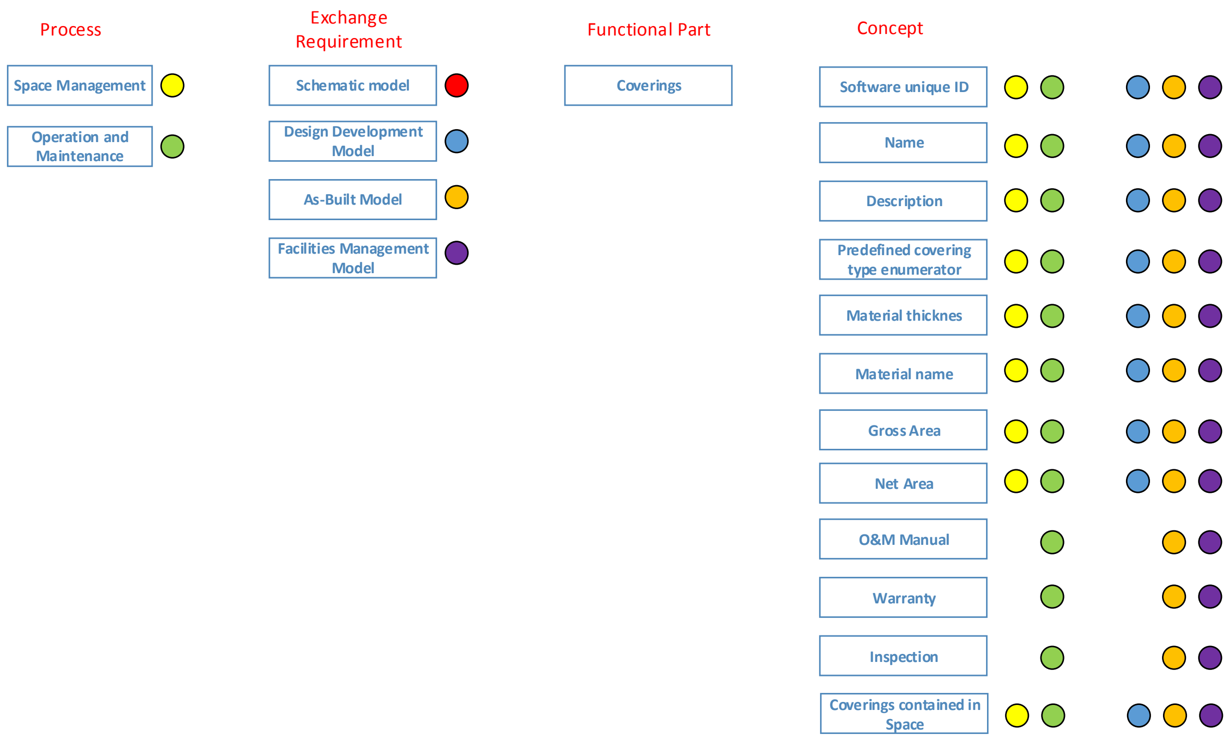
C.11 Concepts for the functional part Windows



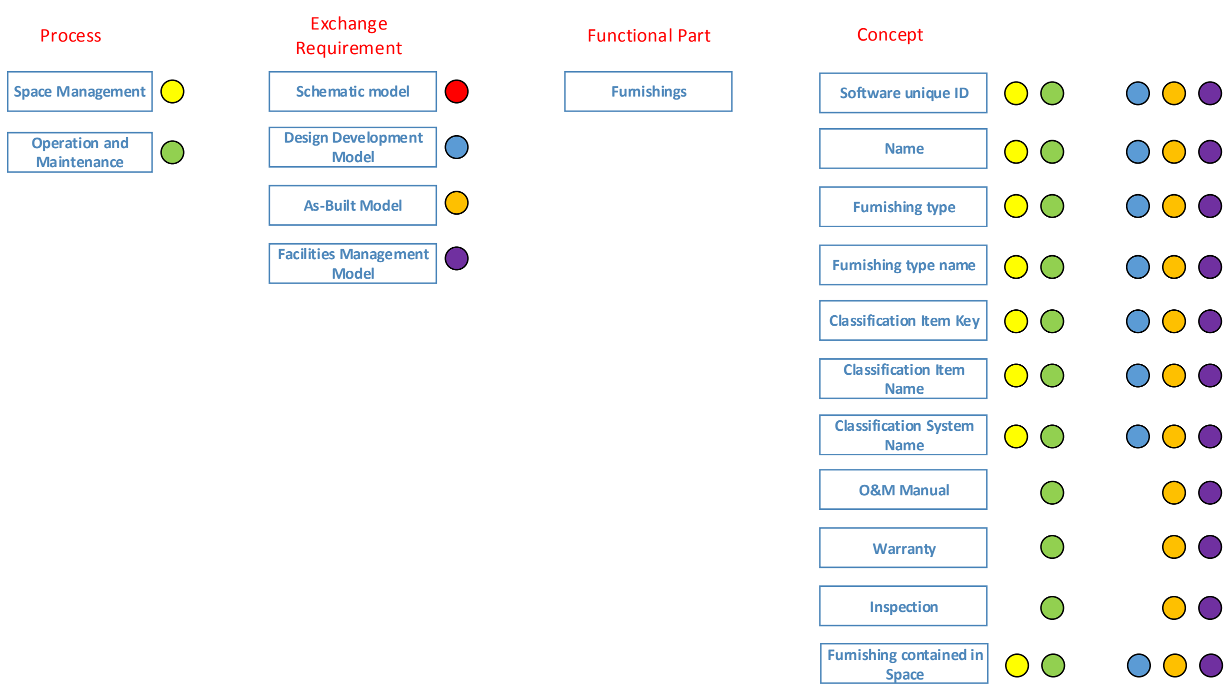
C.12 Concepts for the functional part Doors



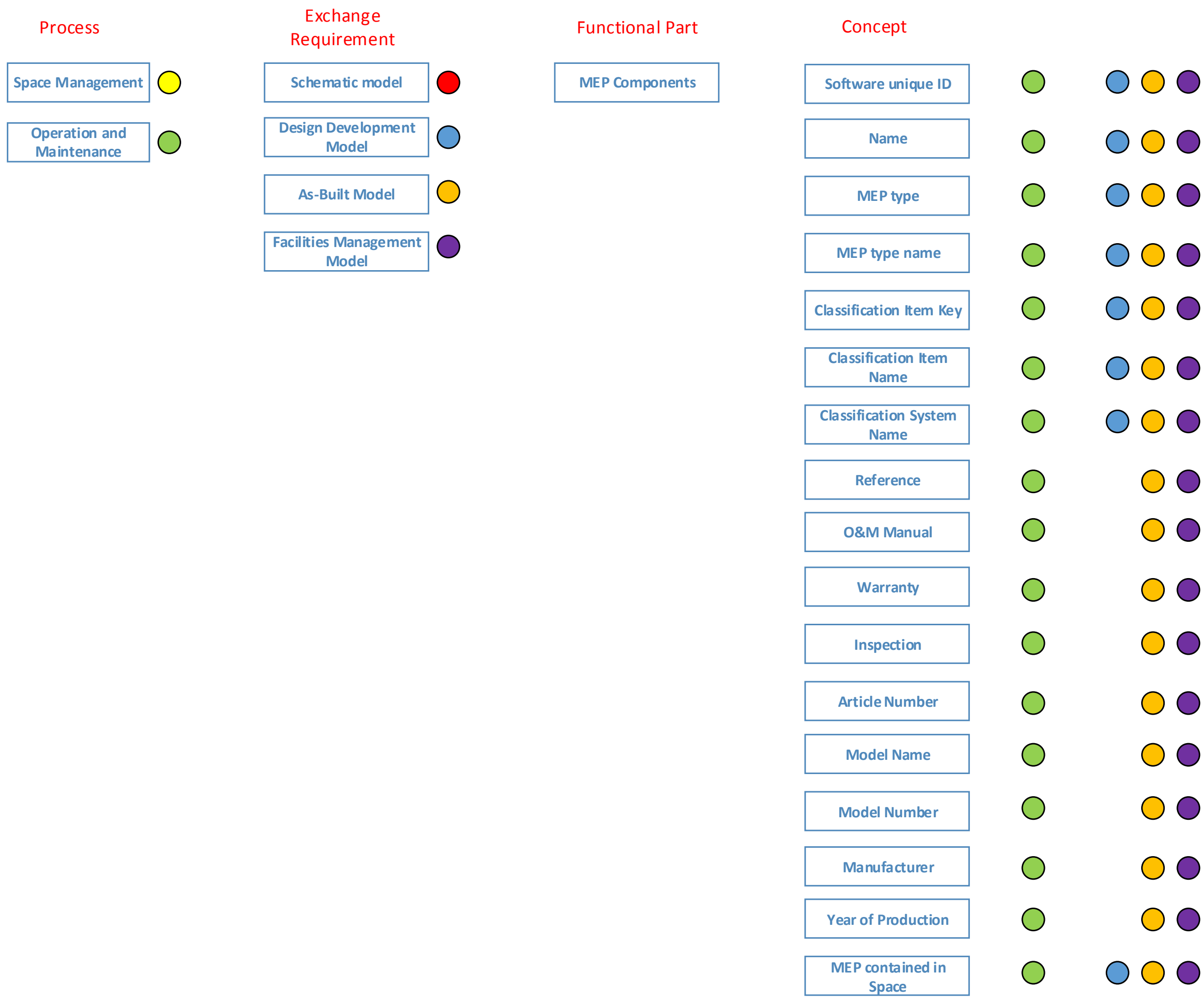
C.13 Concepts for the functional part Coverings



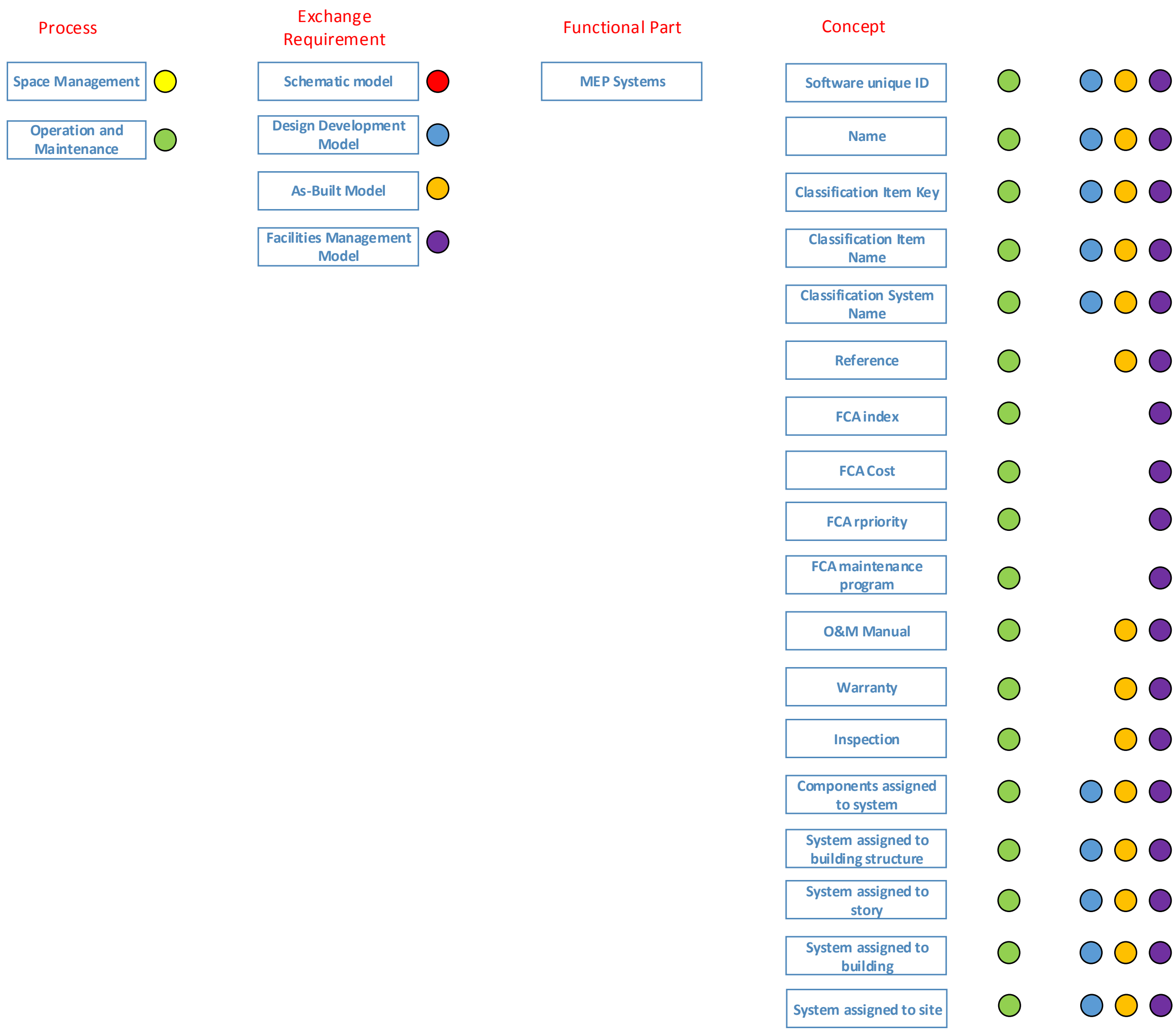
C.14 Concepts for the functional part Furnishings



C.15 Concepts for the functional part MEP Components



C.16 Concepts for the functional part MEP Systems



Appendix D. Concepts Bindings Definition Table

Object type / Group / Attribute	Definition	IFC Model Representation	Defined by
Project		ifcProject	
Project Attributes			
Software unique ID	Object identifier, to identify the software object	ifcProject.GlobalID	Software
Number	User assigned number or ID	ifcProject.Name	User
Name	User assigned name	ifcProject.LongName	User
Project Units			
Length unit	Default unit for all the length measures in the data set	ifcProject.UnitsInContext	User
Area unit	Default unit for all the area measures in the data set	ifcProject.UnitsInContext	User
Volume unit	Default unit for all the area measures in the data set	ifcProject.UnitsInContext	User
Project Decomposition			
Site contained in project	Link to the top level node of the spatial structure. Being a site.	ifcRelAggregates	Software
Building contained in project	Link to the top level node of the spatial structure. Being a building.	ifcRelAggregates	Software
Site		ifcSite	
Site Attributes			
Software unique ID	Object identifier, to identify the software object	ifcSite.GlobalID	Software
Number	User assigned number or ID	ifcSite.Name	User
Name	User assigned name	ifcSite.LongName	User
Site Address			
Address	Address lines	ifcSite.Address.AddressLines	User
City	City name	ifcSite.Address.Town	User
State	State name	ifcSite.Address.Region	User
Zip	Postal Code	ifcSite.Address.PostalCode	User
Spatial Decomposition			
Site contained in project	Backlink to the project as highest node in the project structure	IfcRelAggregates with RelatingObject = IfcProject	Software
Building contained in project	Reference to all buildings that are situated in this site.	IfcRelAggregates with RelatingObject = IfcBuilding	Software
Building		ifcBuilding	
Building Attributes			
Software unique ID	Object identifier, to identify the software object	ifcBuilding.GlobalID	Software
Number	User assigned number or ID	ifcBuilding.Name	User
Name	Designer assigned name	ifcBuilding.LongName	User
Building Address (only if there is no site)			
Address	Address lines	ifcBuilding.Address.AddressLines	User
City	City name	ifcBuilding.Address.Town	User
State	State name	ifcBuilding.Address.Region	User
Zip	Postal Code	ifcBuilding.Address.PostalCode	User
Building Properties			
Age	Year of construction	IfcPropertySingleValue (Pset_BuildingCommon, YearOfConstruction)	User
Landmark Status	Landmark or not	IfcPropertySingleValue (Pset_BuildingCommon, IsLandmarked)	User
Spatial Decomposition			
Building contained in project	Backlink to the project as highest node in the project structure	IfcRelAggregates with RelatingObject = IfcProject	Software
Building contained in site	Either contained in a site, or if no site is available, directly in the project	IfcRelAggregates with RelatingObject = IfcSite	Software
Building Storey contained in building	Storeys in the building, should be at least one storey		Software

Object type Group Attribute	Definition	IFC Model Representation	Defined by
Building Storey		ifcBuildingStorey	
Building Storey Attributes			
Software unique ID	Object identifier, to identify the software object	ifcBuildingStorey.GlobalID	Software
Number	User assigned number or ID	ifcBuildingStorey.Name	User
Name	Designer assigned name	ifcBuildingStorey.LongName	User
Elevation	Building storey datum (relative to the building)	ifcBuildingStorey.Elevation	User
Building Storey Base Quantities			
Net Height	Height of the story from the top of the slab to the bottom of the ceiling	IfcQuantityLength.Name="NetHeight"	User
Storey height	Height of the story from the top of the slab below to the bottom of the slab above	IfcQuantityLength.Name="StoreyHeight"	User
Spatial Decomposition			
Building storey contained in the building	Mandatory relation for the spatial structure	IfcRelAggregates with RelatingObject = IfcProject	Software
Space contained in building storey	Mandatory relation for the spatial structure	IfcRelAggregates with RelatingObject = IfcSite	Software

Object type / Group / Attribute	Definition	IFC Model Representation	Defined by
Space		ifcSpace	
Space Attributes			
Software unique ID	Object identifier, to identify the software object	ifcSpace.GlobalID	Software
Short Name	Designer assigned name or short number	ifcSpace.Name	User
Long Name	Room name	ifcSpace.LongName	User
Internal/External	Indication whether it is an internal or external space	IfcSpace.InteriorOrExteriorSpace	User
Space Attributes			
Classification item key	Classification key	ifcClassificationReference.ItemReference	Software
Classification item name	Classification name	ifcClassificationReference.ItemName	User
Classification system name	Name of the classification system	ifcClassificationReference.ItemSystem	User
Space Base Quantities			
FinishCeilingHeight	clear height of the room (from top of flooring to bottom of ceiling	IfcQuantityLength.Name= "FinishCeilingHeight"	Software
NetFloorArea	sum of all usable floor areas covered by the space	IfcQuantityArea.Name= "NetFloorArea"	Software
NetCeilingArea	sum of all ceiling areas covered by the space	IfcQuantityArea.Name= "NetCeilingArea"	Software
NetWallArea	sum of all wall areas covered by the space	IfcQuantityArea.Name= "NetWallArea"	Software
Space Properties			
Space Common Properties	Properties that are specified in the standard property definitions (or a relevant subset of)	IfcPropertySet with Name = "Pset_SpaceCommon"	
Flooring	name of flooring (material finish).	IjcPropertySingleValue with Name = "FloorCovering"	User
Ceiling	name of ceiling (material finish).	IjcPropertySingleValue with Name = "CeilingCovering"	User
Cladding	name of cladding (material finish).	IjcPropertySingleValue with Name = "WallCovering"	User
Capacity	**Capacity of the space (if designed to host users)**	**IjcPropertySingleValue with Name = "SpaceCapacity"**	**User**
Department	**Organization department whom space is assigned**	**IjcPropertySingleValue with Name = "Department"**	**User**
Space Utilization Index		**IjcPropertySingleValue with Name = "SUI"**	**User**
Occupant	**Name of permanent occupant(s) of the space**	**IjcPropertySingleValue with Name = "Occupant"**	**User**
Maintenance Cost	**Cost of maintenance related to the space**	**IjcPropertySingleValue with Name = "MaintenanceCost"**	**User**
Lease Cost	**Lease charges for the use of the space**	**IjcPropertySingleValue with Name = "LeaseCost"**	**User**
Operation Cost	**Cost of utilities for the space operation**	**IjcPropertySingleValue with Name = "OperationCost"**	**User**
Spatial Decomposition			
Space contained in Building Storey	Space as part of the building structure	IfcRelAggregates with .RelatingObject = IfcBuildingStorey,	Software
Spatial Container			
Elements contained in Space	Furniture and equipment fully contained in space	IfcRelContainedInSpatialStructure with .RelatingStructure = SELF, and RelatedElements=[IfcFurnishingElement, IfcBuildingElementProxy, IfcDistributionElement etc]	Software
Coverings contained in Space	Covering elements of the space	IfcRelContainedInSpatialStructure with .RelatingStructure = SELF, and RelatedElements=[IfcCovering, other covered elements]	Software
Doors/Windows contained in Space	Doors, Windows assigned by a 1:1 containment relationship	IfcRelContainedInSpatialStructure with .RelatingStructure = SELF, and RelatedElements=[IfcDoor, IfcWindow]	Software
Doors/Windows bounding Spaces	Doors, Windows assigned by a 1:2 boundary relationship (mandatory, if no containment)	IfcRelSpaceBoundary with RelatingSpace=SELF, and RelatedElements=IfcDoor OR IfcWindow	Software

Object type / Group / Attribute	Definition	IFC Model Representation	Defined by
Covering		ifcCovering	
Covering Attributes			
Software unique ID	Object identifier, to identify the software object	ifcCovering.GlobalID	Software
Name	Individual element name	ifcCovering.Name	User
Description	Covering description	ifcCovering.Description	User
Predefined covering type enumerator	Covering type as assigned to the individual element	IfcCovering.PredefinedType	User
Covering Material			
Material		IfcMaterial, or IfcMaterialLayerSet (through relationsip IfcRelAssociatesMaterial)	User
Material thickness	thickness of the material layer, many layers can be defined	IfcMaterialLayer.LayerThickness	User
Material name	name of the material, for multi-layer coverings, each layer has a material name	IfcMaterial.Name	User
Covering Base Quantities			
Gross Area	Total area of the covering.	IfcQuantityArea.Name="GrossArea"	Software
Net Area	Area of the covering taking into account openings.	IfcQuantityArea.Name="NetArea"	Software
Covering Properties			
Covering common properties	Properties that are specified in the standard property definitions (or a relevant subset of)	IfcPropertySet with Name = "Pset_CoveringCommon"	
O&M Manual	**url link to the O&M documentation**	**IjcPropertySingleValue with Name = "OperationAndMaintenance"**	**User**
Warranty	**url link to the warranty documentation**	**IjcPropertySingleValue with Name = "Warranty"**	**User**
Inspection	**url link to the inspection/startup documentation**	**IjcPropertySingleValue with Name = "Inspection"**	**User**
Spatial Container			
Coverings contained in Space	A covering element has to be contained in a space (and not in a building storey)	IfcRelContainedInSpatialStructure with .RelatingStructure = SELF, and RelatedElements=[IfcCovering, other covered elements]	Software

Object type / Group / Attribute	Definition	IFC Model Representation	Defined by
Window		ifcWindow	
Covering Attributes			
Software unique ID	Object identifier, to identify the software object	ifcWindow.GlobalID	Software
Name	Individual element name	ifcWindow.Name	User
Window Type			
Window type	Reference to the common window type used for all occurrences of the same window type	IfcWindowStyle (through relationship IfcRelDefinesByType)	User
Name	Individual type name	IfcWindowStyle.Name	User
Operation type	The configuration of the window panels, single panel, double panel, triple panel, and whether horizontal or vertical	IfcWindowStyle.OperationType	User
Panel operation type	The way the window is operated	IfcWindowPanelProperties.OperationType (through IfcWindowStyle.HasPropertySets	User
Window Material			
Material	base material for the window	IfcMaterial (through relationsip IfcRelAssociatesMaterial)	User
Window base quantities			
Width	Width of the window lining, to be provided for rectangular windows.	IfcQuantityLength.Name="Width"	Software
Height	Height of the window lining, to be provided for rectangular windows.	IfcQuantityLength.Name="Height"	Software
Area	Area of the window, including frame and lining.	IfcQuantityArea.Name="Area"	Software
Window Properties			
Window Common Properties	Properties that are specified in the standard property definitions (or a relevant subset of)	IfcPropertySet with Name = "Pset_WindowsCommon"	
Fire resistance	Properties that are specified in the standard property definitions (or a relevant subset of)	IfcPropertySingleValue with Name = "FireRating"	User
Glazing area	String according to national building code	IfcPropertySingleValue with Name = "GlazingAreaFraction"	User
Internal/External	Provided as a fraction of the total window area	IfcPropertySingleValue with Name = "IsExternal"	User
O&M Manual	**url link to the O&M documentation**	**IjcPropertySingleValue with Name = "OperationAndMaintenance"**	**User**
Warranty	**url link to the warranty documentation**	**IjcPropertySingleValue with Name = "Warranty"**	**User**
Inspection	**url link to the inspection/startup documentation**	**IjcPropertySingleValue with Name = "Inspection"**	**User**
Spatial Container			
Windows contained in Building Story	A window can be contained in a building storey, if there is a boundary relationship to one or two spaces	IfcRelContainedInSpatialStructure with .RelatingStructure = IfcBuildingStorey, and RelatedElements=[IfcWindow, other contained elements]	User
Windows contained in Space	A window can be contained in a space, then no additional boundary relation is further analyzed	IfcRelContainedInSpatialStructure with .RelatingStructure = IfcStorey, and RelatedElements=[IfcWindow, other contained elements]	User
Space Boundary			
Window bounding Space	A window can bound a single space (if external window, or two spaces (if internal window)	IfcRelSpaceBoundary with RelatingSpace=IfcSpace, and RelatedElements=SELF	User

Object type / Group / Attribute	Definition	IFC Model Representation	Defined by
Door		ifcDoor	
Covering Attributes			
Software unique ID	Object identifier, to identify the software object	ifcDoor.GlobalID	Software
Name	Individual element name	ifcDoor.Name	User
Door Type			
Door type	Reference to the common Door type used for all occurrences of the same door type	IfcDoorStyle (through relationship IfcRelDefinesByType)	User
Name	Individual type name	IfcDoorStyle.Name	User
Operation type	The configuration of the door panels, single panel, double panel, triple panel, and whether horizontal or vertical	IfcDoorStyle.OperationType	User
Door Material			
Material	base material for the door	IfcMaterial (through relationsip IfcRelAssociatesMaterial)	User
Door base quantities			
Width	Width of the door lining, to be provided for rectangular Doors.	IfcQuantityLength.Name="Width"	Software
Height	Height of the door lining, to be provided for rectangular Doors.	IfcQuantityLength.Name="Height"	Software
Area	Area of the Door, including frame and lining.	IfcQuantityArea.Name="Area"	Software
Door Properties			
Door common properties	Properties that are specified in the standard property definitions (or a relevant subset of)	IfcPropertySet with Name = "Pset_DoorCommon"	
Fire resistance	String according to national building code	IfcPropertySingleValue with Name = "FireRating"	User
Glazing area	Provided as a fraction of the total Door area	IfcPropertySingleValue with Name = "GlazingAreaFraction"	User
Fire exit	Boolean choice whether fire exit door or not	IfcPropertySingleValue with Name = "FireExit"	User
Internal/External	Indication whether it is an internal or external (part of the facade) door	IfcPropertySingleValue with Name = "IsExternal"	User
O&M Manual	**url link to the O&M documentation**	**IjcPropertySingleValue with Name = "OperationAndMaintenance"**	**User**
Warranty	**url link to the warranty documentation**	**IjcPropertySingleValue with Name = "Warranty"**	**User**
Inspection	**url link to the inspection/startup documentation**	**IjcPropertySingleValue with Name = "Inspection"**	**User**
Spatial Container			
Doors contained in Building Story	A door can be contained in a building storey, if there is a boundary relationship to one or two spaces	IfcRelContainedInSpatialStructure with .RelatingStructure = IfcBuildingStorey, and RelatedElements=[IfcDoor, other contained elements]	User
Doors contained in Space	A door can be contained in a space, then no additional boundary relation is further analyzed	IfcRelContainedInSpatialStructure with .RelatingStructure = IfcStorey, and RelatedElements=[IfcDoor, other contained elements]	User
Space Boundary			
Door bounding Space	A door can bound a single space (if external Door, or two spaces (if internal Door)	IfcRelSpaceBoundary with RelatingSpace=IfcSpace, and RelatedElements=SELF	User

Object type / Group / Attribute	Definition	IFC Model Representation	Defined by
Furnishing		ifcFurnishing	
Furnishing Attributes			
Software unique ID	Object identifier, to identify the software object	ifcFurnishing.GlobalID	Software
Name	Individual element name	ifcFurnishing.Name	User
Furnishing Type			
Furnishing type	Reference to the common furniture type used for all occurrences of the furniture	IfcFurnishingElement.ObjectType	User
Furnishing type name	Individual type name	IfcFurnishingType.Name	User
Furnishing Classification			
Classification		IfcClassificationReference (through relationship IfcRelAssociatesClassification)	User
Classification Item Key	Key of classification item within the classification system	IfcClassificationReference.ItemReference	User
Classification Item Name	Clear name of the classification item	IfcClassificationReference.Name	
Classification System Name	Name of the classification system	IfcClassification.Name (through IfcClassificationReference.ReferencedSource)	
Furnishing Properties			
Furnishing common properties	**Properties that are specified in the standard property definitions (or a relevant subset of)**	**IfcPropertySet with Name = "Pset_FurnishingCommon"**	
O&M Manual	**url link to the O&M documentation**	**IjcPropertySingleValue with Name = "OperationAndMaintenance"**	**User**
Warranty	**url link to the warranty documentation**	**IjcPropertySingleValue with Name = "Warranty"**	**User**
Inspection	**url link to the inspection/startup documentation**	**IjcPropertySingleValue with Name = "Inspection"**	**User**
Spatial Container			
Furnishing contained in Space	A furnishing can be contained in a space,	IfcRelContainedInSpatialStructure with .RelatingStructure = IfcStorey, and RelatedElements=[IfcFurnishing, other contained elements]	User

Object type / Group / Attribute	Definition	IFC Model Representation	Defined by
Building Service Elements (MEP)		ifcDistributionElement	
MEP Attributes			
Software unique ID	Object identifier, to identify the software object	ifcDistributionElement.GlobalID	Software
Name	Individual element name	ifcDistributionElement.Name	User
MEP Type			
MEP type	Reference to the common furniture type used for all occurrences of the element	IfcDistributionElement.ObjectType	User
MEP type name	Individual type name	IfcDistributionElement.Name	User
MEP Classification			
Classification		IfcClassificationReference (through relationship IfcRelAssociatesClassification)	User
Classification Item Key	Key of classification item within the classification system	IfcClassificationReference.ItemReference	User
Classification Item Name	Clear name of the classification item	IfcClassificationReference.Name	
Classification System Name	Name of the classification system	IfcClassification.Name (through IfcClassificationReference.ReferencedSource)	User
MEP Properties			
MEP common properties	Properties that are specified in the standard property definitions (or a relevant subset of)	IfcPropertySet with Name = "Pset_DistributionFlowElementCommon"	
Reference	Reference ID for this specific instance	IfcPropertySingleValue with Name = "Reference"	User
O&M Manual	**url link to the O&M documentation**	**IjcPropertySingleValue with Name = "OperationAndMaintenance"**	**User**
Warranty	**url link to the warranty documentation**	**IjcPropertySingleValue with Name = "Warranty"**	**User**
Inspection	**url link to the inspection/startup documentation**	**IjcPropertySingleValue with Name = "Inspection"**	**User**
MEP Manufacturer Properties	Properties that are specified in the manufacturer property definitions (or a relevant subset of)	IfcPropertySet with Name = "Pset_ManufacturerTypeInformation"	User
Article Number	Article number or reference	IfcPropertySingleValue with Name = "ArticleNumber"	User
Model Name	The name of the manufactured item as used by the manufacturer.	IfcPropertySingleValue with Name = "ModelReference"	User
Model Number	The model number and/or unit designator assigned by the manufacturer	IfcPropertySingleValue with Name = "ModelLabel"	User
Manufacturer	The organization that manufactured and/or assembled the item.	IfcPropertySingleValue with Name = "Manufacturer"	User
Year of Production	The year of production of the manufactured item.	IfcPropertySingleValue with Name = "ProductionYear"	User
Spatial Container			
MEP contained in Space	A MEP can be contained in a space,	IfcRelContainedInSpatialStructure with .RelatingStructure = IfcStorey, and RelatedElements=[IfcDistributionElement, other contained elements]	User

Object type / Group / Attribute	Definition	IFC Model Representation	Defined by
Any other furniture, fixture and equipment		ifcBuildingElementProxy	
Proxy Attributes			
Software unique ID	Object identifier, to identify the software object	ifcBuildingElementProxy.GlobalID	Software
Name	Individual element name	ifcBuildingElementProxy.Name	User
Proxy Type			
Proxy type	Reference to the common furniture type used for all occurrences of the element	IfcBuildingElementProxy.ObjectType	User
Proxy type name	Individual type name	IfcBuildingElementProxy.Name	User
Proxy Classification			
Classification		IfcClassificationReference (through relationship IfcRelAssociatesClassification)	User
Classification Item Key	Key of classification item within the classification system	IfcClassificationReference.ItemReference	User
Classification Item Name	Clear name of the classification item	IfcClassificationReference.Name	
Classification System Name	Name of the classification system	IfcClassification.Name (through IfcClassificationReference.ReferencedSource)	User
Proxy Properties			
Proxy common properties	Properties that are specified in the standard property definitions (or a relevant subset of)	IfcPropertySet with Name = "Pset_DistributionFlowElementCommon"	
Reference	Reference ID for this specific instance	IfcPropertySingleValue with Name = "Reference"	User
O&M Manual	**url link to the O&M documentation**	**IjcPropertySingleValue with Name = "OperationAndMaintenance"**	**User**
Warranty	**url link to the warranty documentation**	**IjcPropertySingleValue with Name = "Warranty"**	**User**
Inspection	**url link to the inspection/startup documentation**	**IjcPropertySingleValue with Name = "Inspection"**	**User**
Proxy Manufacturer Properties	Properties that are specified in the manufacturer property definitions (or a relevant subset of)	IfcPropertySet with Name = "Pset_ManufacturerTypeInformation"	User
Article Number	Article number or reference	IfcPropertySingleValue with Name = "ArticleNumber"	User
Model Name	The name of the manufactured item as used by the manufacturer.	IfcPropertySingleValue with Name = "ModelReference"	User
Model Number	The model number and/or unit designator assigned by the manufacturer	IfcPropertySingleValue with Name = "ModelLabel"	User
Manufacturer	The organization that manufactured and/or assembled the item.	IfcPropertySingleValue with Name = "Manufacturer"	User
Year of Production	The year of production of the manufactured item.	IfcPropertySingleValue with Name = "ProductionYear"	User
Spatial Container			
Proxy contained in Space	A proxy can be contained in a space,	IfcRelContainedInSpatialStructure with .RelatingStructure = IfcStorey, and RelatedElements=[IfcBuildingElementProxy, other contained elements]	User

Object type / Group / Attribute	Definition	IFC Model Representation	Defined by
Zone as a logical grouping of spaces		ifcZone	
Zone Attributes			
Software unique ID	Object identifier, to identify the software object	ifcZone.GlobalID	Software
Name	Individual element name	ifcZone.Name	User
Spatial Zone Assignment			
Grouping of system components			
Spaces assigned to zone	Assignment of individual spaces that belong to the zone for organizational or other purposes	IfcRelAssignsToGroup with .RelatingGroup = IfcZone, and .RelatedObjects = all IfcSpace's belonging to the zone	User
System as a logical grouping of components		ifcSystem	
System Attributes			
Software unique ID	Object identifier, to identify the software object	ifcSystem.GlobalID	Software
Name	Individual element name	ifcSystem.Name	User
System Classification			
Classification	System classification	IfcClassificationReference (through relationship IfcRelAssociatesClassification)	User
Classification Item Key	Key of classification item within the classification system	IfcClassificationReference.ItemReference	User
Classification Item Name	Clear name of the classification item	IfcClassificationReference.Name	User
Classification System Name	Name of the classification system	IfcClassification.Name (through IfcClassificationReference.ReferencedSource)	User
System Properties			
System common properties	**Properties that are specified in the standard property definitions (or a relevant subset of)**	**IfcPropertySet with Name = "Pset_SystemCommon"**	
Reference	Reference ID for this specific instance	IfcPropertySingleValue with Name = "Reference"	User
FCA index	**Facility condition assessment index**	**IfcPropertySingleValue with Name = "fcaIndex"**	**User**
FCA Cost	**Facility condition assessment cost**	**IfcPropertySingleValue with Name = "fcaCost"**	**User**
FCA priority	**Facility condition assessment priority**	**IfcPropertySingleValue with Name = "fcaPriority"**	**User**
FCA maintenance program	**Facility condition assessment maintenance program**	**IfcPropertySingleValue with Name = "fcaProgram"**	**User**
O&M Manual	**url link to the O&M documentation**	**IjcPropertySingleValue with Name = "OperationAndMaintenance"**	**User**
Warranty	**url link to the warranty documentation**	**IjcPropertySingleValue with Name = "Warranty"**	**User**
Inspection	**url link to the inspection/startup documentation**	**IjcPropertySingleValue with Name = "Inspection"**	**User**
Component System Assignment			
Grouping of system components			
Components assigned to system	Assignment of individual components that belong to the MEP system	IfcRelAssignsToGroup with .RelatingGroup = IfcSystem, and .RelatedObjects = all components (subtypes of IfcDistributionElement) belonging to the system, or IfcSystem's being sub-systems	Software
System Services Buildings			
System assigned to building structure	Assignment of the system to the level of the building structure, it serves	IfcRelAssignsToGroup with .RelatingGroup = IfcSystem, and .RelatedBuildings = levels of the building structure	Software
System assigned to story	Assignment of the system to the level of the story, it serves (horizontal and single story systems)	with .RelatedBuildings = [1...n] IfcBuildingStorey	Software
System assigned to building	Assignment of the system to the level of the building, it serves (Vertical systems)	with .RelatedBuildings = [1...n] IfcBuilding	Software
System assigned to site	Assignment of the system to the level of the site for delivering services to the building	with .RelatedBuildings = [1...1] IfcSite	Software

Appendix E. Validation Survey

Section 1/3

My name is Sergio Alvarez, I am a Doctoral Student at Worcester Polytechnic Institute (WPI). I am conducting research to explore the information that in the context of educational facilities has value to the owner/operator and that can be delivered at the end of the construction stage through a Building Information Modeling (BIM)-enabled digital handover process. (Click here for a more detail description of my research)

Because you attended the SCUP conference in Boston on March 2014 I would like to collect your views and thoughts with regards to the some aspects addressed in my research. Therefore, I am kindly asking you to respond to this short survey. It may take you no more than 10 minutes. The results of the survey will be summarized in my thesis report and I would like to share these with you if you so desire.

Are you a staff member of the facilities management department at your institution?

- ❍ Yes (1)
- ❍ No (2)

If No Is Selected, Then Skip to End of Block

Identify all areas of education offered by your institution:

- ❑ Arts and Humanities (1)
- ❑ Business (2)
- ❑ Social Sciences (3)
- ❑ Education and Teaching (4)
- ❑ Health & Medicine (5)
- ❑ Science & Technology (6)
- ❑ Trades and Careers (7)
- ❑ Engineering / Architecture (8)
- ❑ Computing and Information Technology (9)
- ❑ Other(s), please specify (10) ____________________

What is the size of your institution in terms of Number of Students?

- ❍ less than 5,000 students (1)
- ❍ between 5,000 amd 15,000 (3)
- ❍ more than 15,000 (4)

Does your institution use BIM technology to support any phase (design, construction, space management, and/or operation and maintenace?

- ❍ Yes (1)
- ❍ No (2)

Section 2/3 (IF NOT USING BIM)

After construction is completed, relevant information about the design and construction of the project is handed over the facilites management department. This information is documented in different ways. Indicate the different ways (in percentage of total) used by contractors to deliver this information to your facilites management department:

______ The information is delivered printed on paper documents (4)
______ The information is delivered via digital media as a set of scanned documents, excel files, or CAD files (3)
______ The information is delivered via digital media through COBie files in spreadsheet format (2)
______ Other (specify) (1)

Answer this question in the context of the predominant way used by contractors to deliver documentation at the end of construction (as noted in the previous question).Once the facilities department receives the handover package, indicate, for each specific document listed below, how convenient is to use this information (that is, sorting, organizing, re-typing, converting, importing and getting the information ready) to support the operation and maintenance of the facilities?

	Very Convenient (1)	Somehow convenient (2)	Somehow inconvenient (3)	Not convenient at all (4)	Does not apply (5)
Maintenance records (1)	❍	❍	❍	❍	❍
Maintenance schedules (2)	❍	❍	❍	❍	❍
As-Built drawings (3)	❍	❍	❍	❍	❍
Warranties (4)	❍	❍	❍	❍	❍
Operation and maintenance manuals (5)	❍	❍	❍	❍	❍
Space Management Information (6)	❍	❍	❍	❍	❍
Facilities and equipment conditions (7)	❍	❍	❍	❍	❍

For each specific document listed below, select the methods used by the facilities management department to handle this infromation after construction has been completed (Select all that apply)

	Using computerized system (2)	Using electronic spreadsheets (Excel or similar) (3)	Using scanned files or printed documents (4)	Other (6)	Don´t know (7)
Maintenance records (1)	❑	❑	❑	❑	❑
Maintenance schedules (2)	❑	❑	❑	❑	❑
As-Built drawings (3)	❑	❑	❑	❑	❑
Warranties (4)	❑	❑	❑	❑	❑
Operation and maintenance manuals (5)	❑	❑	❑	❑	❑
Space Management Information (6)	❑	❑	❑	❑	❑
Facilities end equipment conditions (7)	❑	❑	❑	❑	❑

How do you locate the corresponding warranty documentation for an equipment that needs to be claimed? (Select the one that better reflects your case)

- ❍ Physically verifying the brand, serial number, model of the equipment, then locating the physical or scanned document in the filing system (1)
- ❍ Using the computerized facilities management system that stores infromation about the location, room, make, serial number, model of the equipment, then locating the physical or scanned document in the filing system. (2)
- ❍ Using the computerized facilities management system where the information about the equipment can be located, then accessing the warranty documentation that is electronically linked to the system (6)
- ❍ Other (5) ____________________

Section 3/3

List the three most important software applications that are used by the facilities management to support the operation and maintenance process at your institution?

- ❑ 1 (2) ____________________
- ❑ 2 (3) ____________________
- ❑ 3 (4) ____________________

From the list below, select at least three (but no more than five) areas for maintenance and operation having the higher impact on the cost of maintnenance at your institution.

- ❑ HVAC (1)
- ❑ CARPENTRY (2)
- ❑ ELECTRICAL (3)
- ❑ PLUMBING (4)
- ❑ KEYS AND LOCKS (5)
- ❑ GLASS/WINDOWS (7)
- ❑ PAINTING (8)
- ❑ POWER PLANTS (9)
- ❑ GROUNDS (10)
- ❑ PEST CONTROL (11)
- ❑ CUSTODIAL (12)
- ❑ MOVING (13)
- ❑ ELEVATOR (14)
- ❑ APPLIANCE (15)
- ❑ SIGNAGE (16)
- ❑ RECYCLING (17)
- ❑ WASTE MANAGEMENT (18)
- ❑ COMMUNICATIONS / NETWORK (20)

Thanks for taking the time to answer the survey. Would you like to receive the results and analysis of the survey once all the surveys have been processed?

- ❍ No (1)
- ❍ Yes (please provide the e-mail for sending the results and analysis of the survey) (2)

  ____

Section 2/3 (IF USING BIM)

For which project development phases does your organization use BIM or require the designer/contractor the use of BIM? (Select all that apply)

- ❑ Schematic Design (1)
- ❑ Design Development (2)
- ❑ Construction (3)
- ❑ Operation and Maintenance (4)

After construction is completed, relevant information about the design and construction of the project is handed over the facilities management department. This information is documented in different ways. Indicate the different ways (in percentage of total) used by contractors to deliver this information to your facilites management department:

______ The information is delivered via a BIM model (1)
______ The information is delivered via digital media through COBie files in spreadsheet format (2)
______ The information is delivered via digital media as a set of scanned documents, excel files, or CAD files (3)
______ The information is delivered printed on paper documents (4)
______ Other (specify) (5)

Answer this question in the context of the predominant way used by contractors to deliver documentation at the end of construction (as noted in the previous question).Once the facilities department receives the handover package, indicate, for each specific document listed below, how convenient is to use this information (that is, sorting, organizing, re-typing, converting, importing and getting the information ready) to support the operation and maintenance of the facilities?

	Very Convenient (1)	Somehow convenient (2)	Somehow inconvenient (3)	Not convenient at all (4)	Does not apply (5)
Maintenance records (1)	❍	❍	❍	❍	❍
Maintenance schedules (2)	❍	❍	❍	❍	❍
As-Built drawings (3)	❍	❍	❍	❍	❍
Warranties (4)	❍	❍	❍	❍	❍
Operation and maintenance manuals (5)	❍	❍	❍	❍	❍
Space Management Information (6)	❍	❍	❍	❍	❍
Facilities end equipment conditions (7)	❍	❍	❍	❍	❍

For each specific document listed below, select the methods used by the facilities management department to handle this information after construction has been completed (Select all that apply)

	Using BIM (1)	Using computerized system (2)	Using electronic spreadsheets (Excel or similar) (3)	Using scanned files or printed documents (4)	Other (6)	Don´t know (7)
Maintenance records (1)	❑	❑	❑	❑	❑	❑
Maintenance schedules (2)	❑	❑	❑	❑	❑	❑
As-Built drawings (3)	❑	❑	❑	❑	❑	❑
Warranties (4)	❑	❑	❑	❑	❑	❑
Operation and maintenance manuals (5)	❑	❑	❑	❑	❑	❑
Space Management Information (6)	❑	❑	❑	❑	❑	❑
Facilities end equipment conditions (7)	❑	❑	❑	❑	❑	❑

How do you locate the corresponding warranty documentation for an equipment that needs to be claimed? (Select the one that better reflects your case))

- Physically verifying the brand, serial number, model of the equipment, then locating in the warranty filing system the proper warranty (1)
- Using the computerized facilities management system that stores the location, room, make, serial number, model of the equipment, then locating the physical or scanned document in the filing system. (2)
- Using the computerized facilities management system where the information about the equipment can be located, then accessing the warranty documentation that is electronically linked to the system (3)
- Using a BIM model of the facility to visually locating the equipment and the corresponding information about the brand, serial number and model of the equipment, then locating in the warranty filing system the corresponding warranty (4)
- Using a BIM model of the facility to visually locating the equipment and the corresponding information about the brand, serial number and model of the equipment, then accessing the warranty documentation that is electronically linked to the system (8)
- Other (6) ____________________

Thank you, would you please forward the link to this survey to someone in your organization who is a staff member of the facilities management department