Generating As-is Building Information Models for Facility Management by Leveraging Heterogeneous Existing Information Sources: A Case Study

Bo GU[1], Semiha ERGAN[2], Burcu AKINCI[3]

[1] Ph.D. Student, Dept. of Civil & Environmental Engineering, Carnegie Mellon University 5000 Forbes Ave. Porter Hall 121, Pittsburgh PA, 15213; email: bgu@andrew.cmu.edu

[2] Assistant Professor, Dept. of Civil & Environmental Engineering, Carnegie Mellon University 5000 Forbes Ave. Porter Hall 118K, Pittsburgh PA, 15213; email: semiha@cmu.edu

[3] Professor, Dept. of Civil & Environmental Engineering, Carnegie Mellon University 5000 Forbes Ave. Porter Hall 123K, Pittsburgh PA, 15213; bakinci@cmu.edu

ABSTRACT

Inadequate information interoperability in facility management (FM) activities costs time and money being wasted for searching for the needed information in many different data sources. An integrated building information model (BIM), depicting as-is conditions, has a high potential to minimize such wastes. However, facility managers still face the challenge of generating as-is building information models for existing facilities. A main problem with current approaches for generating as-is BIMs is that they mainly focus on capturing and providing geometric information. Many other types of information are missing, such as equipment warranty and technical parameters. The research described in this paper targets the generation of accurate and semantically-rich as-is BIMs by leveraging heterogeneous existing information sources, such as drawings and operation and maintenance manuals. This approach was investigated through detailed case studies done in two old academic buildings. Existing information obtained from documents has been compared to Industry Foundation Classes (IFC), COBie and the data generated from a BIM authoring system. The comparative analysis results reveal several information gaps among different sources.

Keywords: as-is model, building information modeling, facility management, model generation, industry foundation classes, case study

INTRODUCTION

Existing data sources, such as drawings and operation and maintenance (O&M) manuals, are valuable to building owners and managers during the service life of their facilities (Eastman et al. 2011; Galleher et al. 2004; Akcamete et al. 2009). However, inefficiencies in utilizing and updating facility documents result in unnecessary cost to building owners (Klein et al. 2012). An often-cited report from NIST found that there is an estimated $1.58 billion annual cost due to the lack of data interoperability (Gallaher et al. 2004). 57.5% of the money is wasted during operation and maintenance (O&M) phase, and building owners and operators have to pay 67.3% of the total cost. All of these numbers signify the importance of finding an efficient way to collect, access, and update building information.

Building Information Modeling (BIM) technology and associated processes target streamlining the sharing, integration, tracking and maintenance facility information (Eastman et al. 2011; Teicholz et al. 2013). However, in current practice, BIM is mainly used at the design/construction phases (Tang et al. 2010) and changes that occur in construction and O&M phases are not always captured and reflected in BIM (Liu et al. 2012).

Various methods have been developed to capture as-is building information that can be grouped under traditional and novel technologies. Examples of traditional technologies are measurement tapes, digital cameras and theodolite to capture changes (e.g., Klein et al. 2012; Liu et al. 2012), whereas novel technologies, such as laser scanners and cameras, include vision-based reality capture and development of as-built models (e.g., Tang et al. 2010; Klein et al. 2012). In relation to generation of as-built models, research has been done on automatically generating 3D models from paper-based and CAD-based architectural drawings (e.g., Yin et al. 2009).

The approaches mentioned above mainly focus on capturing geometric and spatial information associated with a building. However, other types of information, such as equipment warranty and technical parameters, are also needed for a complete BIM for facility management. Existing data sources, such as commissioning reports, energy audit documents, O&M manuals cover such semantic information about facilities. The authors propose to generate as-is BIMs through utilizing existing data sources. A unique challenge with the existing data sources is that data sources can overlap in terms of the information they contain about an asset or a system, and contain multiple values for the same information over time, resulting in data source reliability issues. Hence, the challenge need to be addressed while generating as-is BIMs from existing data sources.

In order to illustrate the feasibility and challenges associated with the generation of as-is BIMs from existing documentation, we conducted case studies in two legacy buildings. BIMs for both buildings were generated based on available existing documents. Existing information obtained from these documents has been compared to the information that are required to generate a BIM, specified by Industry Foundation Classes (IFC), COBie and a commercially-available model generation software system.

CASE STUDY

We selected two legacy academic buildings for which we generated BIM from existing documents. An overview of the selected buildings is shown in Table 1. We focused on the mezzanine floor in Buidling1 and the first floor in Building 2, to identify and analyze the available documentation. These floors were selected because over the last decades, several major renovation projects took place, along with a large number of small projects, resulting in more changes to be tracked as compared to the other floors. There were various documents available from different projects over time, which enabled the authors to assess what types of information were available in these sources to create the BIMs, and what additional information would still be needed for generating as-is BIM and yet not contained in these documents.

Table 1. Overview of Buildings

	Building 1	Building 2
Type	Academic building	Academic building
Size	Six-floor with15,477 sq ft	Five-floor with 36,849 sq ft
Age	102 years	52 years

Hundreds of document sets were found (see Table 2 and 3) from facility management (FM) department's archive and its server. Those documents had a wide range of time stamps, from 1911 to 2013. In addition, they were stored in different formats. Old drawings (e.g. original design) were hand-writing paper-based, then scanned to image or PDF files. Some recent drawings were in the native CAD format. Some old hand-drawn drawings are blurry, which are not easy to read when compared to CAD files. However, the old drawings are important since they provide information that recent drawings do not have. Typically, the recent drawings of renovation projects only include floor plans with notes for demolition and additional work. Information, such as elevations, could only be found in original design drawings.

Besides drawings, other documents were found for Building 1, such as O&M manuals, equipment submittals and commissioning reports. However, for Building 2, we are not able to find any of these documents. According to facility mangers, this is a common situation due to several reasons. As-built documents sometimes were not handed over to FM department on time after construction. Several years ago, a large number of paper-based documents were damaged and lost due to an unexpected flood. In addition, sometimes paper-based documents were not returned by FM personnel after they looked them up. All these causes again reveal drawbacks of traditional paper-based information management.

Table 2. Available Existing Documents for Building 1

Year	Quantity	Documents	Format
1911	55	Original design drawings	Scanned image
1915	35	Drawings of Major addition on east and west wings	Scanned image
1952 to 2011	309	Drawings of small renovation projects	Scanned PDF and CAD
2013	6	Current floor plans from Property Accounting Service	PDF and CAD
1983, 1990, 1992, 2000, 2012	7	Operation & Maintenance Manuals	Paper and Scanned PDF
1983, 1997, 2001, 2002, 2012	6	Test Reports	Paper
1997, 2002, 2008, 2012	5	Submittals	Paper
2012	1	Pre-Commissioning Report	Scanned PDF
Total	**424**		

Table 3. Available Existing Documents for Building 2

Year	Quantity	Documents	Format
1961	75	Original design drawings	Scanned image and converted CAD
1962-1999	79	Small renovation drawings	scanned image and CAD in PDF
2001, 2002	59	Renovation site pictures	image
2001, 2002, 2003, 2005	324	Drawings of Small renovation projects	CAD
2011	33	Drawings of renovation Project	CAD, PDF and word document
2013	18	Current floor plans from Property Finance	CAD and PDF
Total	**588**		

The authors used a commercial modeling tool to create BIMs of the selected floors based on these existing documents. Information related to geometry, location, orientation and decomposition of components was extracted from the available drawings. Additional information, such as equipment operation times, component material information was added from other available documents, such as equipment submittals. However, some recurrent issues were found when generating models. For several attributes required by the modeling tool, corresponding values were not available in the existing data sources. Similarly, some available information from the documents could not match any attribute in the modeling environment, due to the fact that the tool was designed for modeling purpose only. These issues revealed that there are gaps between the information contained in the existing documentations and the information required by the modeling tool.

In order to fully understand the information overlaps and gaps between what is available and what is required to generate BIMs for existing facilities, the need for further analysis became apparent. Both Industry Foundation Classes (IFC) and Construction Operation Building Information Exchange (COBie) are widely utilized to represent information for facilities management domain and have been used in this study to generate the list of required information. Information extracted from existing documentation, properties in the modeling tool, IFC schema and COBie sheets were reviewed and mapped to each other to understand information overlaps and gaps.

COMPARATIVE ANALYSIS RESULTS

In IFC schema and COBie spreadsheets, every defined attribute has been considered as one information item. In the modeling tool, every parameter that would require a value has been defined as an information item. In the existing documentation, every piece of information that could provide a specific value for components in a BIM has been considered as one information item.

Five types of mappings have been defined based on the observations that the authors had in the mapping process. The first three types were considered as matching items, while the last two were not.

- **Perfect Matching** (1:1): An information item that corresponds to a property of an object is represented with the same parameter in IFC, COBie, the modeling tool and existing documents.
- **Secondary Matching** (1:1, 1:*, *:*): An information item that corresponds to a property of an object is represented with different parameters in IFC, COBie, modeling tool and existing documents. For example, to describe the whole area of a wall, the modeling tool uses a parameter called 'wall area' whereas IFC uses the sum of two parameters, 'footprint area' and 'side area'.
- **Extended Matching** (1:1, 1:*): An information item that corresponds to a property of an object is represented by deriving its value from other properties in order to map to an item in IFC and COBie, modeling tool and existing documents. For example, IFC has a property called 'wall volume'. Although there is no such information item in existing documents, it can be calculated based on existing information about a wall's geometry.
- **Partial Matching** (1:1, 1:*): An information item that corresponds to a property of an object is represented with a parameter that is partially mapped to another parameter in IFC, COBie, the modeling tool and existing documents. For example, for functionalities of walls, there were four enumerations in the modeling tool, but only two were described in IFC.
- **Not Matching** (1:0): An information item that corresponds to a property of an object is represented with a parameter that does not match with any other parameters in the sources.

In this study, four objects were selected from each case study to represent components for different domains. Walls were used to represent architectural and structural elements, spaces and zones were used to represent spatial elements and fan coil units were used to represent mechanical elements. The comparison results are discussed in the following section.

Comparison for Architectural and Structural Elements – Wall Case

Based on the models created, architectural walls had the largest number of counts among all the components. In addition, according to the records kept by the FM department, architectural walls have been involved in most renovation projects. Although structural elements were not affected from renovation projects as much as the architectural components, they were still studied in this work in order to understand the information overlaps and gaps from structural components perspective. In both IFC schema and the modeling tool, a wall object has additional structural properties when it is defined as a structural wall. Therefore, wall objects were selected to represent both architectural and structural components. Table 4 shows the total amount of information items extracted for both buildings. The required information from the modeling tool and IFC does not change by instances. Since the same type of component, a wall, is selected, the amounts of information items required by these two sources for different buildings are the same. On the other hand, the information contained in existing documents varies for different buildings. Therefore, the amount of existing information extracted changed.

Table 4. Amount of Information Extracted from Different Sources --Walls

Source	Building 1	Building 2
Existing Documents	74	65
Modeling Tool	98	98
IFC2x4 and COBie	132	132

Main objects that were examined in IFC2x4 were IfcWall, IfcWallType, IfcOpening, IfcMaterialLayerSet, IfcMaterialLayer and their property sets. The authors compared information defined in IFC and COBie with the information required by the modeling tool and information available in existing documentation. The mapping results are shown in Figure 1 and Figure 2.

For Building1, 27.27 % of the information form the standards was not only required by the modeling tool, but also available in the existing documentation, which is mainly about material and geometric information. 25.00% of the information was required by the modeling tool, but not available in the existing documents. 9.09% of the information from the standards was not required by the modeling tool, but available in the existing documentation. There were also 38.64% items defined in IFC and COBie that were not available in any of the existing data sources. The missing information was mainly from the property sets defined for walls, including walls' condition, environmental impact indicators/values, manufacturer occurrence/type information, packing instructions, service life, warranty, fabrication details for precast concrete elements and precast information in general. These were missing from the existing documents either because the structural walls were not precast members (cast in place in this case), or additional field surveys were required to get the information (e.g., wall conditions) and no such information was available.

The results of Building 2 show the similar percentage patterns and underlying findings. However, the percentages of information extracted from existing documents are slightly smaller than Building 1, which means that there is less information found for Building 2. Examples of these missing items include wall fire rating and detailed information of the design firm (e.g. address, telephone).

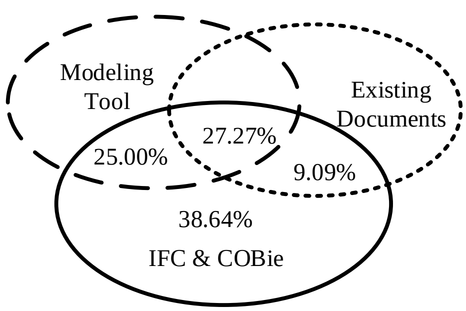

Figure 1 Comparative Analysis Results for Walls -- Building 1

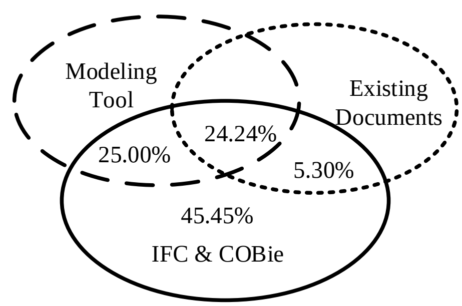

Figure 2 Comparative Analysis Results for Walls – Building 2

Comparison for Mechanical Elements -- Fan Coil Unit Case

Fan coil units (FCU) were selected as an example to represent mechanical components. Fan coil units are among the critical components of HVAC systems and several documentations were available for fan coil units for this facility due to a recent and completed FCU replacement project in the building. The existing documents found at the FM department included submittal data sheets, O&M manuals, floor plans with space distribution, pre-commissioning reports and balance testing reports. In addition to these, a service manual for this particular FCU product was downloaded and reviewed from the manufacturer's website. Table 5 shows the quantities of information items extracted from the sources.

Table 5. Amount of Information Extracted from Different Sources – FCUs

Source	Building 1	Building 2
Existing Documents	53	14
Modeling Tool	44	44
IFC2x4 and COBie	564	564

In IFC, HVAC components, such as fan coil units, are represented as IfcUnitaryEquipment, which represents an assembly. Different HVAC systems require different assembly components and according to the service manual, this particular FCU consisted of three main parts: fan, coil and pipe. Therefore, five classes were studied, namely IfcUnitaryEquipment, IfcDistributionElement, IfcFan, IfcCoil and IfcDistributionPort, along with their property sets. The results of the mapping process for the FCUs are provided in Figure 3 and 4.

For Building 1, a large amount, 86.69% of the information required to represent FCUs were neither available in the existing data sources nor was incorporated in the modeling tool. One of the main reasons is that IFC defines very detailed aggregation relationships as discussed in the previous paragraph, which causes the main bulk of the missing information. In addition, nine property sets were defined for each of the five IFC classes analyzed and constituted 49.6%of the information items extracted from IFC. These include condition, sound generation parameters, environmental impact indicators /values, manufacturer occurrence /type information, packing instructions, service life and warranty information. Another main reason for this gap is the level of details used to represent of the same information in these sources. In the existing data sources, most information is described at the assembly level, not at individual component level. For example, one can only find unified warranty information for the whole FCU product in the existing documents, whereas in IFC, each component has its own warranty information. Similarly, performance characteristics were defined at the assembly level in the existing documents, however when mapped to IFC, they were mapped at component level (e.g., cooling capacity defined for FCU could only be mapped to IfcCoil and was not related to the other components in the assembly). Among the rest of the information that matches to existing sources or modeling tool, 1.95% matches to both sources, which are mainly geometric information, 4.61% is required in the modeling tool, but not available in the existing documents and 9.75% is only available in the data sources but not asked within the modeling environment.

For Building 2, the percentage for available existing information is much smaller than Building 1 (1.77% vs. 9.75%). This is mainly because the authors were not able to find any existing equipment related documents (e.g. submittals and O&M manuals) as mentioned in Section 2. These documents mainly contain information about equipment performance parameters, which is the major part of required information according to IFC and COBie.

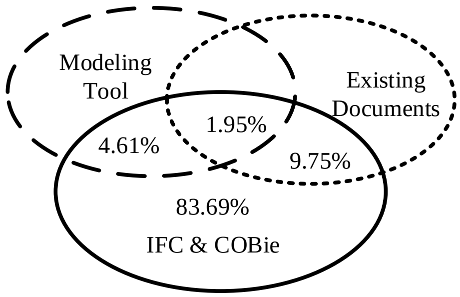

Figure 3 Comparative Analysis Results for Fan Coil Units-- Building 1

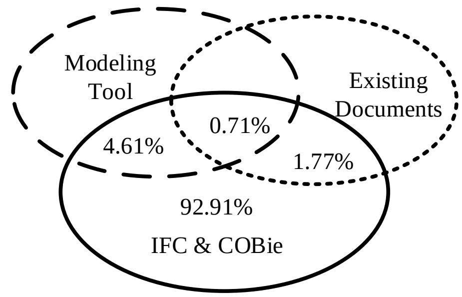

Figure 4 Comparative Analysis Results for Fan Coil Units – Building 2

Comparison for Spatial Elements—Rooms, Spaces and Zones

Spatial elements studied in this work included rooms, spaces and zones. Both IFC and the modeling tool have similar definition for this group of objects; which is defined as a group of spaces with the same architectural and environmental properties. The modeling tool uses room notion to maintain architectural parameters, such as area and volume; and uses both zone and space notions exclusively for energy demand and loads analysis, such as people loads and mechanical airflow. While in IFC, IfcSpace object is used for both architecture and MEP disciplines, and IfcZone object has properties only related to service life (buildingSMART 2013).

Various existing data sources were explored to extract data, such as floor plans, finishing schedules, elevation drawings, and space inventory database. For example, the authors found room names in the floor plan, room heights in elevation drawings, the room finishing materials in finish schedules, and the room occupancy information from the campus space inventory database. Table 6 shows the quantity of information items extracted from the sources.

Table 6. Amount of Information Extracted from Different Sources – Spaces

Source	Building 1	Building 2
Existing Information	26	30
Modeling Tool	94	94
IFC2x4 and COBie	194	194

When compared with information items from IFC, COBie and the modeling tool, all items from the existing data sources were matched with IFC, COBie and the modeling tool. However, all of them were related to the architecture aspects, and only accounted for 13.4% in IFC and COBie and 27.6% in the modeling tool. The missing items that created the biggest gap are information related to the thermal properties, such as energy demand and load analysis, which consist a large part of information in IFC, COBie and the modeling tool. 47.4% of items in IFC are thermal related properties, and 78.9% items in the modeling tool are MEP related parameters. Normally, this kind of information is generated during design development (Fallon and Palmer 2007), which were not available for buildings studied.

Figure 5 and Figure 6 shows the mapping results of information items extracted from IFC and COBie to information available in the existing documents/drawings and the modeling environment. For Building 1, 57.73% items, defined as requirements, did not match to information contained in any of the existing sources. The nature of such information was mainly related to property sets, such as property agreement and space parking, which were not applicable for this case building or as thermal load design criteria, space thermal load history, which were not available. 13.40% defined in IFC and COBie was available in existing data sources and required in the modeling tool, whereas 28.97% of the information was not available in the existing documents, but required in the modeling tool.

The results of Building 2 show the similar percentage patterns and underlying findings. The amount of existing information is slightly greater than Building 1. This is mainly because a design specification is found, which specified the required cooling and heating temperature and humidity for various types of spaces.

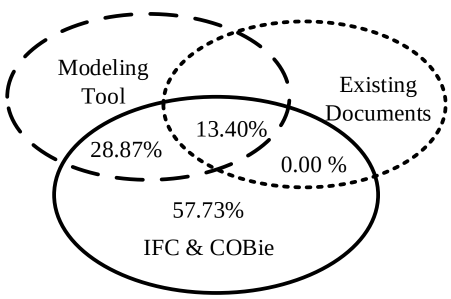

Figure 6 Comparative Analysis Results for Spaces – Building 1

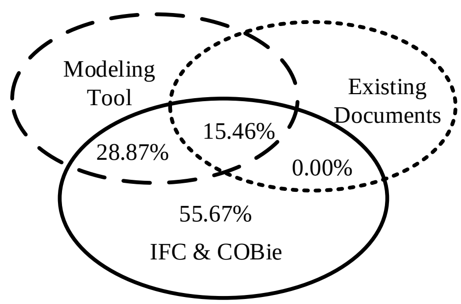

Figure 5 Comparative Analysis Results for Spaces -- Building 2

DISCUSSION AND CONCLUSION

This paper described case studies of generating as-is BIM for a facility that is in operation for a long time by utilizing existing documentation. The information items extracted from the existing documentation were compared to a set of requirements for generating a model. These requirements were extracted from IFC, COBie and a modeling tool.

The initial results reveal information gaps among those sources, and motivate further research in this area. Though in very small fraction as compared to what is defined in IFC/COBie, there were still information items available in the drawings/documents that could not be matched to IFC/COBie or the modeling tool. Such information mainly included operational processes defined in text format for major equipment and construction detailing in drawings. A large part of information defined for components in IFC and COBie, ranging from 38.6% to 83.7% (depending on the component type), does not match with information contained in other sources. This large information gap exists mainly due to three reasons: (a) the information covered in IFC schema and COBie is too comprehensive and detailed for existing documents to provide- especially relationships in IFC, (b) the information that is stored in the existing documents is at the assembly level whereas the information defined in IFC is at the individual component level, (c) the specific characteristics of the facility analyzed (where there was no documentation available to cover information specific to a certain aspect of the components analyzed). For example, energy analysis reports were not available for the case facility, resulting in unmapped items for this category.

An important point is that when requirements of as-is BIM is defined from data standards, the information gap is observed to be large, since IFC specification is designed to represent building information throughout the lifecycle of a facility and not all of the properties in IFC are required for FM daily activities. Therefore, it is essential to identify what information is required for FM so that such information can be represented in the as-is BIMs. The next steps in this work will focus on defining what information is needed to generate as-is BIM from FM activities perspective and proposing an approach to integrate available information from heterogeneous data sources to generate accurate and semantically-rich as-is BIMs.

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