Benefits of 6D BIM for Facilities Management Departments for Construction Projects – A Case Study Approach

Omid Davtalab[a] and Jose L. Delgado[b]

[a] Facilities Management Department, University of Southern California, United States of America
[b] Facilities Management Department, University of Southern California, United States of America
E-mail: davtalab@usc.edu, jldelgad@usc.edu

Abstract -

Building Information Modeling (BIM) has been widely adopted in Architecture, Engineering, Construction, and facilities management (AEC/FM) industry. Recently, 3D BIM models are commonly used; however, there is still some debates going on upon the necessity of 6D BIM utilization, which is the as-built BIM model linked with operations and maintenance (O&M) information of building's components. Owners are always faced with the dilemma of the benefits of 6D BIM application in their projects' lifecycle. In this paper, the timesaving benefits of 6D BIM models in facilities management (FM) practices during a building's life cycle are studied. 6D model application in operations control and maintenance, the two main responsibilities of FM departments, is studied in this paper. Several scenarios, tested in a building owned by USC facilities management department, are designed to determine the timesaving benefits of 6D model utilization. These scenarios are divided into two major categories: operations control and maintenance. Data acquisition from Computer Room Air Conditioning (CRAC) units, Chillers, and Air Handling Units (AHU) for operations control and two maintenance scenarios of occupant dissatisfaction from office temperature and leakage in chilled water lines have been studied in this paper. The time needed to accomplish the explained scenarios has been measured using two available approaches of 3D/2D models and 6D models. Based on achieved results, possible timesaving benefits of 6D model application are explored and presented.

Keywords – Building Information Modeling, Facilities Management, 6D Model, Operations, Maintenance

1 Introduction

Building Information Modeling (BIM) is widely used in construction industry from design to operations and maintenance phases of a building's lifecycle. Facilities management (FM) departments can utilize BIM technology for coordinated, consistent, and computable building information and knowledge management [1]. In a study by National Institute of Standards and Technology (NIST), efficiency losses are about $15.8 billion per year in U.S. capital facilities industry [2]. This efficiency loss is resulted from inadequate interoperability among computer-aided design, engineering, and facility management software systems. The majority of this loss, i.e. $9 billion per year, is related to operations and maintenance phase of the buildings' lifecycle in which FM departments play the most important role [2].

Although the term BIM has been defined many times before, but a clear definition prior to the discussion is yet necessary. Based on the definition by Gu et al. [3], "Building Information Modeling (BIM) is an IT enabled approach that involves applying and maintaining an integral digital representation of all building information for different phases of the project lifecycle in the form of a data repository". BIM utilization in FM departments changes the traditional methods of documentation, maintenance, control, and analysis among the FM practices. FM departments strive to apply BIM technology to lower the operations control and maintenance costs, providing more precise control systems, and consistently delivering cost effective services for the occupants of the buildings. Thus, adoption of BIM technology has been an issue of great importance for FM departments in order to enhance the effectiveness of the operations and maintenance practices.

BIM technology applications, software, and programs have evolved over the years in construction industry. FM departments utilize some of these applications, software, and programs for operations and maintenance purposes such as electronic document management systems (EDMS), digital direct control (DDC), building automation systems (BAS), remote operations control, emergency service responses, and energy management systems (EMS).

In this paper, the timesaving benefits of 6D BIM models, i.e. the as-built BIM model linked with operations and maintenance (O&M) information and specifically real time operational data of building's components, for FM practices are studied. 6D model application in Operations control and Maintenance, the two main responsibilities of FM departments, are studied in this paper.

2 Research methodology

The present paper used a case study driven approach to evaluate the timesaving benefits of 6D model application in FM departments. Several scenarios, tested in a building owned by USC facilities management department, are designed to determine the timesaving benefits of 6D model application. Scenarios are designed based on the common and daily tasks of FM departments. These scenarios are divided into two major categories: operations control and maintenance. Data acquisition from Computer Room Air Conditioning (CRAC) units, Chillers, and Air Handling Units (AHU) for operations control (Section 5) and two maintenance scenarios of occupant dissatisfaction from office temperature and leakage in chilled water lines (Section 6) have been studied in this paper. The time needed to accomplish the explained scenarios has been measured using two available approaches of 3D/2D models and 6D models. Based on achieved results and their comparisons, possible timesaving benefits of 6D model application are explored.

The studied building in this paper, in which scenarios are tested, is located in Los Angeles, California. This building is owned by University of Southern California (USC). USC facilities management department holds the responsibility of operations control and maintenance of this building as well as the other buildings owned by USC.

The web-based software used in this paper is called EcoDomus [4]. EcoDomus is cloud-based software providing 3D visual ability of all the assets in a facility with linked-in data (6D model). This software provides services for project management (PM) and facilities management (FM) purposes. EcoDomus FM used in this study utilizes a 3D interface enabling interactive virtual preventive maintenance and operating inspections [4]. It enables the ability of creating intelligent BIM models from preliminary 3D models in which all the objects existing in a building are data assigned with documents attached to them that makes the operations and maintenance phase of a building's life cycle more efficient and precise.

EcoDomus FM, as middleware software, enables real-time integration of BIM with Building Automation Systems, such as Honeywell, and Accruent FAMIS that are used in USC facilities management department [4]. Using EcoDomus, FM departments are able to monitor their assets' operating conditions in a 3D virtual environment linked with up-to-date data. Using this technology, facility managers are able to execute real time data acquisition and remote operations control of building components.

3 Literature review

During the past years, information and communication technologies have evolved rapidly in Internet and web-based technologies. Collaboration and integration systems have been established in different application domains, including architecture, engineering, construction, and facilities management (AEC/FM) [5]. 6D BIM model is an example of these technologies. Integrated knowledge-based BIM systems can provide advanced useful functions for operations and maintenance of the buildings [5]. Operations and maintenance plan of a building is related to the decisions and actions for maintenance and controlling components of the building. These decisions and actions are aimed at preventing equipment failure with the goal of increasing safety, efficiency, and reliability. [6]. Current building maintenance systems mainly focus on capturing and using the real time information from the building components to support proper maintenance decisions. Failure in capturing and using these information, results in enormous costs due to ineffective decisions [7]. Improvement of interoperability and integrated systems has been studied in several researches to provide better data modeling in FM departments [8, 9]. Several integrated FM models were also developed to represent the requirements of facilities operations and maintenance [10, 11, 12]. Object-oriented model for a facility information system [13], information system for facility management [14], KBS [15], and integrated facilities management information system [16] are the examples of these models.

Operations and maintenance practices in facilities management departments can be divided into two main categories; preventive and corrective. Preventive efforts relate to routine maintenance plan of the buildings while corrective category concerns about the failure and break down in a building operating system [7]. Facilities can be managed in a more comprehensive manner through more integrated FM software [17]. BIM technology can provide variety of benefits in different applications. Locating building components, facilitating real-time data access, and checking maintainability are some of the applications that BIM technology can be utilized in FM department [1]. Using 3D as-built BIM models linked with operational data of building components, i.e. mentioned as 6D BIM models in this paper, provides the ability for FM departments to localize the mechanical, plumbing, electrical, and fire safety (MEPF) components while displaying the data relevant to the operational context [17]. Several researches have discussed about the importance of BIM's visualization and coordination capabilities in different construction projects [18, 19]. Having a 6D BIM model provides the effective and immediate access to building components information. This ability minimizes the labor and saves time for retrieving the useful data and avoids ineffective decisions for FM departments [20].

4 Operations control

There are a lot of components in each building that should be monitored by FM departments in different timely manners. These components belong to all disciplines existing in a building including mechanical, electrical, plumbing, and fire protection (MEPF). Operations control of these components requires data acquisition from them in proper time periods to accurately monitor the condition of each component performance.

4.1 Scenarios

In this part, real time data acquisition process of eight Computer Room Air Conditioning (CRAC) units, four chillers, and seven air handling units (AHU) is tested. These components are being monitored daily to verify whether they are working properly. A problem in each component can result in serious damages and dissatisfaction of building occupants. Data acquisition from a building's components can be done through different approaches. In the present study, two approaches are presented while the time difference between using them is analyzed.

4.1.1 Computer Room Air Conditioning (CRAC) units operations control scenario

CRAC units are devices used in data centers or network rooms. CRAC units maintain the proper temperature, humidity, and airflow distribution in locations where racks of servers and other computer devices are protected. Considering their role for cooling the data centers and network rooms, it is vital for USC FM department to monitor the operations of these units since a little problem in their performance can result in enormous damages.

In this part, data acquisition process for CRAC units is studied through two different approaches, remote method using 6D model and traditional method including physical rounds on the site to directly get the data from the units. This scenario is tested for eight CRAC units in four rounds to compare the duration of each method for real time data acquisition process. The mechanical parameters recorded for data acquisition from CRAC units are shown in table 1. These parameters are recorded on hourly-based periods and therefore, required to be collected 24 times a day.

Table 1 - CRAC Units Mechanical Parameters

TEMPERATURE	Set
	Actual
TEMP. SENSITIVITY	
HUMIDITY	Set
	Actual
HUMIDITY SENSITIVITY	
HIGH TEMP. ALARM	
LOW TEMP. ALARM	
HIGH HUMIDITY ALARM	
LOW HUMIDITY ALARM	

Table 2 shows the time spent on each CRAC unit data acquisition using two different approaches. The travel time must be also taken into account in calculating the total time in traditional method. Obviously, this time is saved when data acquisition process is done from a remote computer using the 6D model. Accuracy of the time measurements is one second since in remote method all durations are less than one minute.

Table 2 - CRAC Units - Duration Measurements

Round Number	CRAC Unit Number	Duration - Using 6D BIM Method (Seconds)	Duration - Using Traditional Method (Seconds)
1	1	45	175
	2	34	150
	3	47	96
	4	35	174
	5	36	165
	6	41	156
	7	39	159
	8	38	165
2	1	42	157
	2	38	160
	3	35	158
	4	41	162
	5	36	154
	6	37	148
	7	35	153
	8	36	152
3	1	39	162
	2	42	151
	3	43	154
	4	39	152
	5	36	159
	6	42	161
	7	40	148
	8	32	157
4	1	36	152
	2	38	155
	3	42	155
	4	36	163
	5	35	152
	6	40	157
	7	36	157
	8	39	150

In traditional method, FM department experts must visit the site and observe the CRAC units one by one while writing down the collected data. Each CRAC unit is equipped with a touch screen pad that provides the required data such as temperature and humidity. However, in the remote method using 6D models, it is possible to monitor the CRAC units in a virtual environment and simply retrieve the real time data for desired parameters from a computer by clicking on each CRAC unit.

Table 3 shows the travel time in each round for observing all the CRAC units using traditional method. This time is the walking time between the CRAC Units excluding the data acquisition period from each unit.

Table 3 - CRAC Units - Traditional Method Travel Times

Round Number	Travel Time (Seconds) Using Traditional Method
1	180
2	190
3	175
4	200

Based on the measurements shown in table 3 and 4, the total time for the whole process of data acquisition in each round is calculated and shown in table 4.

Table 4 -CRAC Units - Total Time Measurements

Round Number	Total Time (Seconds) - 6D BIM Method	Total Time (Seconds) - Traditional Method
1	315	1420
2	300	1434
3	313	1419
4	302	1441

4.1.2 Chillers operations control scenario

Chillers are mechanical components commonly used in large commercial buildings. They use the vapor compression cycle to cool water. The chilled water is circulated through the building via chilled water lines to provide cooling services. The scenario is tested for four chillers. Table 5 shows the mechanical parameters that are daily checked for chillers.

Measurement accuracy in this part is one second the same as the previous part. Table 6 shows the total time for data acquisition from the chillers in a single round.

The travel time in traditional method was 116 seconds that should be added to the total round process.

Table 5 - Chillers Mechanical Parameters

CONDENSATE WATER TEMP.	IN (℉)
	OUT (℉)
CHILLED WATER TEMP.	IN (℉)
	OUT (℉)
CHILLED WATER GPM	
CONDENSATE WATER GPM	
CHILLED WATER SET POINT (℉)	
CURRENT LIMIT SET POINT	
METER LOG (HOURS)	
CONDENSATE DIFFERENTIAL (Psig)	
EVAPORATE DIFFERENTIAL (Psig)	
OIL DIFFERENTIAL (Psig)	
OIL TEMP. (℉)	
Oil Level (0 - 1/4 - 2/4 - 3/4 - 4/4)	
EVAPORATE TEMP. (℉)	

Table 6 - Chillers - Duration Measurements

Chiller Number	Duration (Seconds) Using 6D BIM Method	Duration (Seconds) Using Traditional Method
1	105	523
2	100	500
3	112	490
4	109	510

4.1.3 Air Handling Units (AHU) operations control scenario

AHUs are one of the major mechanical components in buildings. They are responsible for heating, ventilating, and air conditioning. These components distribute supply air through ductworks to VAV boxes, which in terms feed supply diffusers existing in different zones of a building. In the studied building of this paper, there are seven AHUs that are located in different levels of the building. Table 7 shows the parameters that are checked for all these AHUs to control their performance operations.

Table 7 - AHUs Mechanical Parameters

Discharge Air Temperature (DA TEMP)
Supply Fan Variable Frequency Drive Speed (SF VFD Spd)
Supply Fan (SF) CFM
Return Air Temperature (RA TEMP)
Return Fan Variable Frequency Drive Speed (RF VFD Spd)
Return Fan (RF) CFM
Discharge Air (DA) STATIC
Chilled Water Valve % (Chill V %)
Average Maximum Temperature

Durations for data acquisition process are measured for all the AHUs of the building as represented in Table 8.

Table 8 - AHUs - Duration Measurements

AHU Number	Duration (Seconds) Using 6D BIM Method	Duration (Seconds) Using Traditional Method
1	56	275
2	63	264
3	58	270
4	67	282
5	59	267
6	68	276
7	59	271

4.2 Result Analysis

Using the data presented in table 4, 6, and 8, facility managers have the possibility to save approximately 78% for CRAC units, 80% for chillers, and 77% for AHUs in time for data acquisition process using 6D models. Since these components are monitored several times a day, there is a potential to save a huge amount of time by using the 6D BIM technology method.

5 Maintenance

In this section of the paper, two different scenarios related to maintenance of the buildings are studied using two different approaches. In first approach, in order to provide the desired condition in the building, FM department controls the MEPF components of the building from their computer using 6D BIM and remotely adjust the related controlling parameters such as airflow and discharge temperature. The other approach is the traditional control method in which the FM department experts are supposed to visit the components on site and adjust the controlling parameters manually.

5.1 Scenarios

Scenarios, presented in this part, are related to emergency service responses in FM departments for occupants' dissatisfaction and mechanical issues happening on the site such as leakage in chilled water lines. Duration of these service responses has a significant influence on increasing the maintenance costs of the building and occupants' dissatisfaction.

5.1.1 Occupant dissatisfaction report:

In scenario-I of control part, emergency response to dissatisfaction of an occupant from the office temperature is studied. In order to solve the issue and bring back the office temperature to its normal condition, the cooling system must be troubleshot.

Two different approaches for trouble shooting of the mentioned scenario are discussed and compared with each other. In first approach, FM department experts use the 6D BIM model and remotely make adjustments to the components of the air conditioning system to solve the issue. In first step, real time data of the supply diffuser, which is the only supply diffuser located in the test office, is retrieved from EcoDomus FM. Using the 6D BIM model, FM department is able to quickly find the other supply located in the same cooling zone. After retrieving the data for all the diffusers in the same zone, the VAV box feeding all these diffusers is remotely checked in order to identify whether it is working properly or not. The Air Handling Unit (AHU) connected to this VAV box is another component of the cooling system, which requires to be checked as well. The data for all these components are easily retrieved using the 6D BIM approach and the FM department is able to find the problem quickly. Making proper adjustments in cooling system remotely, solves the problem and brings the office temperature back to its normal condition.

In traditional method, systems must be studied through the mechanical 2D drawings or through the 3D BIM model, which does not contain any linked data for components performance parameters such as air flow and discharge temperature. In this case, all the data should be recorded manually from the site using proper tools such as thermometer for measuring temperature and flow hood for measuring the air flow from each supply diffuser. Since VAV boxes are usually located above the ceiling and the supply diffusers are located on the celling, checking the operational parameters of these components is a challenging process, usually requires more than one person to be accomplished.

The accuracy of time measurement in this scenario is one minute. Duration of the whole process in each approach is presented in table 9 as below

Table 9 - Occupant Dissatisfaction Emergency Response - Duration measurements

Approach	Duration of the whole process
6D BIM	34 Minutes
Traditional	2 Hours and 23 Minutes

5.1.2 Leakage in chilled water lines report:

In this scenario, leakage in a chilled water line feeding several CRAC units is reported. Efficiency in solving this issue is extremely important and a late response will result in a huge damage to the network room. Gathering the information from USC FM department experts, the process of fixing the leakage in chilled water lines that are feeding CRAC units is as below:

1. Finding the location of the chilled water line in the building as reported
2. Closing the valves that will stop the water flow to the line having the leakage
3. Finding out the other CRAC units that may be affected by this chilled water line which is closed
4. Making proper adjustments to the other CRAC units to keep the network room or the data center in a normal condition (as a matter of temperature and humidity)
5. Fixing the chilled water line having the leakage
6. Opening the valves and bringing the whole system back to its normal performance

In first approach, FM department experts are able to find the location of the chilled water line and its corresponding valves from the 6D BIM model. These valves are closed manually by sending people to the exact location on the site. The CRAC units that are affected by this issue are found using an existing option in 3D/6D BIM models that highlights the connected components in a system. As a consequence of closing the chilled water line, the operation of several CRAC units fed by the closed line, will be terminated. Thus, in order to keep the network room in a proper condition, required adjustments on other operating CRAC units must be made remotely using 6D BIM model.

In second approach, location of the valves and affected CRAC units must be found in 2D drawings or the 3D model. If there is a 3D model available for the building, the duration of performing this step is equal in both approaches. However, making proper adjustments, retrieving each CRAC unit's data, and determining the network room temperature, humidity, and other parameters in second approach is considerably time consuming compared to the first one. Duration of fixing the chilled water line has been omitted from the measurements since the duration for fixing the pipes by mechanical laborers is identical in both methods.

Accuracy of measurements in this part is one minute the same as the previous scenario and the durations in each approach is shown in table 10.

Table 10 - Leakage in Chilled Water Lines Emergency Response - Duration Measurements

Approach	Duration of the whole process
6D BIM	1 Hours and 35 Minutes
Traditional	3 Hours and 11 Minutes

5.2 Result Analysis:

Based on the measurements for the first scenario related to dissatisfaction of an occupant from the office temperature, using 6D BIM approach solves the issue in 34 minutes while the other one takes 2 hours and 23 minutes. It is clear that using 6D BIM approach saves a lot of time for facility managers and requires only one person to be completed. Results show that it is possible for facility managers to save approximately 76% in time using 6D BIM method. In scenario-II related to the leakage in a chilled water line, using 6D BIM will save approximately 67% in time for facility managers.

6 Conclusion:

This paper presents the timesaving benefits of 6D BIM models application in FM departments using a case study approach. Several scenarios related to operations and maintenance tasks of USC FM department were tested in a building and the results were explored. This case study demonstrates that use of 6D BIM models in FM department results in a possible timesaving up to 80%

in operations and maintenance practices. Future large-scale studies will better evaluate various benefits of 6D BIM models utilization in lifecycle of buildings.

7 Aknowledgement

The authors would like to thank Frank Soria from USC FM department for his helps and commitment in data collection process during this study.

References

[1] Becerik-Gerber B., Jazizadeh F., Li N. and Calis G. Application areas and data requirements for BIM-enabled facilities management. *Journal of construction engineering and management*, 138(3):431-442, 2011.

[2] Gallaher M. P., O'Connor A. C., Dettbarn J. L., Jr. and Gilday L. T. Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry. *National Institute of Standards and Technology*, NIST GCR 04-867, 2004.

[3] Gu N. and London K. Understanding and facilitating BIM adoption in the AEC industry. *Automation in construction*, 19(8):988-999, 2010.

[4] EcoDomus Inc., BIM software for Lifecycle Facilities Management. On-line: http://EcoDomus.com, Accessed: 15/12/2013.

[5] Shen W., Hao Q., Mak H., Neelamkavil J., Xie H., Dickinson J., Thomas R., Pardasani A. and Xue H. Systems integration and collaboration in architecture, engineering, construction, and facilities management: a review. *Advanced Engineering Informatics*, 24(2):196-207, 2010.

[6] Sullivan G. P., Pugh R., Melendez A. P. and Hunt W. D. Operations & Maintenance Best Practices. *Energy Efficiency and Renewable Energy*, 2010.

[7] Motawa I. and Almarshad A. A knowledge-based BIM system for building maintenance. *Automation in Construction*, 29:173-182, 2013.

[8] Yu K., Froese T. and Grobler F. A development framework for data models for computer-integrated facilities management. *Automation in construction*, 9(2):145-167, 2000.

[9] Goulbourne G., Coenen F., Leng P. and Murphy D. Developing association rules in facilities management databases. *Applications and Innovations in Expert Systems*, 230-244, 1999.

[10] Möttönen V.J., Matilainen U. and Parjanen T. Applications of Product Model Theory in Facilities Management. *Proceedings of the International Symposium on Management, Maintenance and Modernization of Building Facilities*, 1183–1190, 1994.

[11] Möttönen V. Information Systems for Facilities Management. *High Technology in Finland*, 72–73, 1995.

[12] Björk B. C. Basic structure of a proposed building product model. *Computer-Aided Design*, 21(2):71-78, 1989.

[13] Bos J.N.W. Software Analysis of a Flexible Object-Oriented Facility Management Information System. *Product and Process Modelling in the Building Industry*, 379–385, 1995.

[14] Majahalme T. *Information System for Facility Management (ISFM)* (Doctoral Thesis) Tampere University of Technology, Department of Civil Engineering, Publications 174, 1995.

[15] Svensson K. *Integrating facilities management information* (Doctoral Thesis) Department of Construction Management and Economics, Royal Institute of Technology, 1998.

[16] Cheng F.F., Patel P. and Bancroft S. Development of an Integrated Facilities Management Information System Based on STEP—A Generic Product Data Model. *Construction Information Technology*, 4(2):1–13, 1996.

[17] Krukowski A. and Arsenijevic D. RFID-based positioning for building management systems. *Circuits and Systems (ISCAS)*, 3569-3572, 2010.

[18] Zuppa D., Issa R. R. and Suermann P. C. BIM's impact on the success measures of construction projects. *Computing in Civil Engineering*, 503-512, 2009.

[19] Manning R. and Messner J. Case studies in BIM implementation for programming of healthcare facilities. *Information Technology in Construction*, 13:246-257, 2008.

[20] Ergen E., Akinci B. and Sacks R. Life-cycle data management of engineered-to-order components using radio frequency identification. *Advanced Engineering Informatics*, 21(4):356-366, 2007.